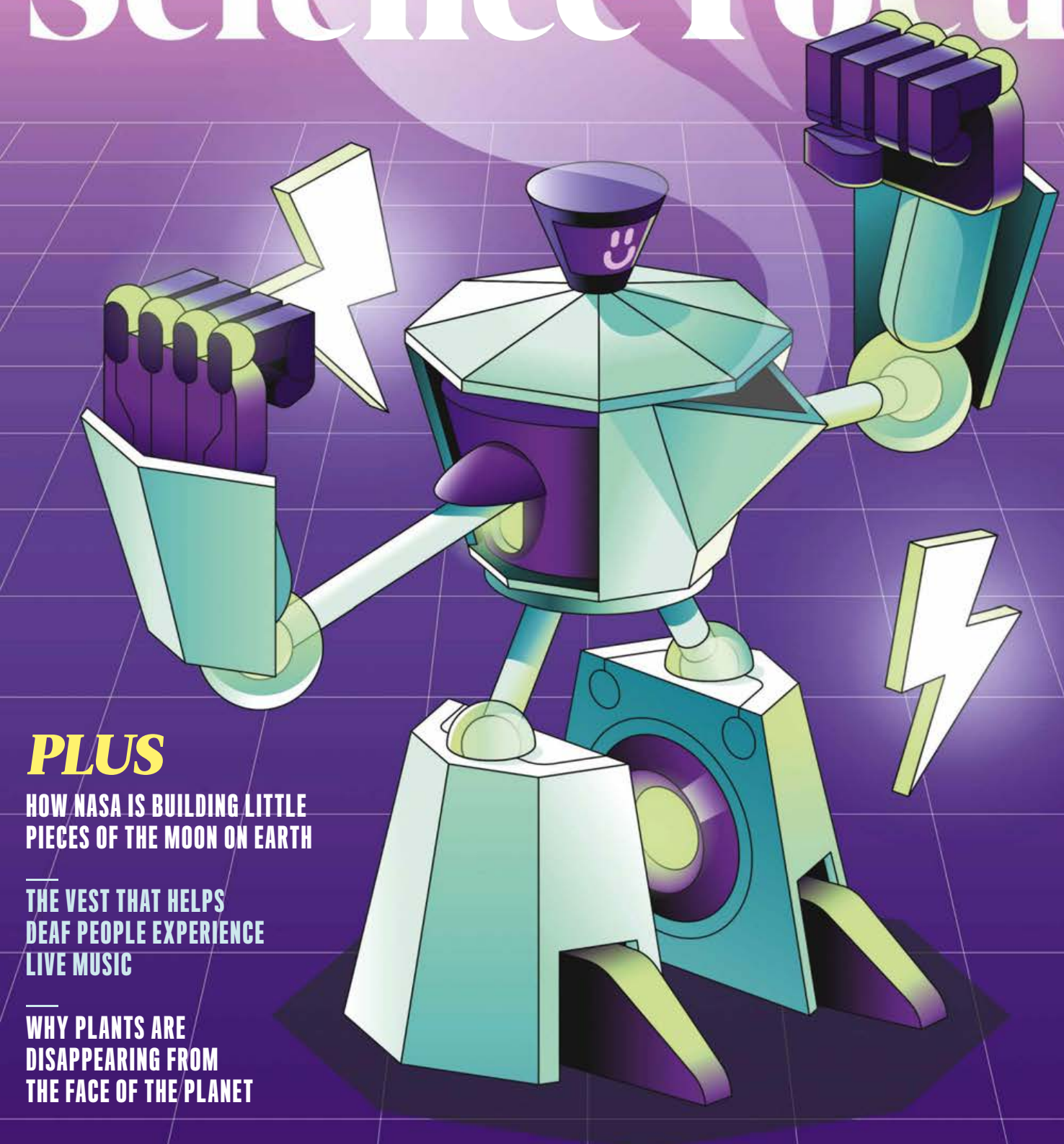
BBC DOCTOR WHO

HOW THE TARDIS COULD FOLD SPACE AND TIME

THE EPISODE THAT PREDICTED THE FUTURE

TIME TRAVELLING THROUGH WORMHOLES

Science Focus



PLUS

HOW NASA IS BUILDING LITTLE PIECES OF THE MOON ON EARTH

THE VEST THAT HELPS DEAF PEOPLE EXPERIENCE LIVE MUSIC

WHY PLANTS ARE DISAPPEARING FROM THE FACE OF THE PLANET

SF
SCIENCEFOCUS.COM
11>
9 772632 284189
ISSUE #398 NOV 2023
UK £5.99

RETHINKING CAFFEINE

HOW THE RIGHT AMOUNT UNLOCKS LIFELONG BENEFITS FOR YOUR BRAIN AND BODY

Medical Research Foundation

Support life-changing medical research.

Join Research Bakers

Many diseases have been cured thanks to medical research, but some areas of health are still in desperate need of support.

Hold a charity bake sale with a scientific twist.

Scan the QR code to find out more.

www.medicalresearchfoundation.org.uk/research-bakers
Reg. charity no. 1138223

FROM THE EDITOR

I don't drink tea. That's the confession I whisper whenever I'm offered one. When people find out I don't partake of the hallowed brew, they tend to look at me as though I've admitted to decorating my walls with locally sourced cat droppings.

I realise I'm totally at odds with British convention here. Unfortunately, no amount of cajoling has changed my mind. Even when some people, for whom a cup of tea is like air, ask: "Well, what do you do instead?"

The reason I don't partake is my gran used to try to hide medicine in cups of tea. Nothing sinister, just an Indian grandmother hoping a chai might make a bitter remedy go down easy. Instead, it just made me wretch at the smell of freshly brewed tea leaves. So now, I get my caffeine via coffee instead. The thing is, when you think about it, it's very rare to find someone who doesn't consume caffeine in one form or another. Whether you get it from tea, coffee, soft drinks or energy drinks, drinking caffeine seems to be almost as ubiquitous a practice as putting salt on your food. It's woven into the fabric of many cultures across the world.

But recently, the tide seems to be turning on caffeine. As many of us struggle with sleep and hear reports about the dangers of consuming too much of the stuff, a cup of your favourite brew has started to feel like a guilty pleasure. Meanwhile high-performance athletes and scientists are beginning to realise that caffeine, ingested in certain quantities, can work as a legal performance-enhancing drug in the short-term and provide significant health benefits in the long-term. So what is caffeine: friend or foe? Read our cover feature, starting on p62, to find out.

Daniel Bennett, Editor

WANT MORE? FOLLOW **SCIENCEFOCUS** ON FACEBOOK X (FORMERLY TWITTER) PINTEREST INSTAGRAM

Is it really better to hope for the best but brace for the worst? →p86

CONTRIBUTORS

DR MATILDA BROWN
Conservation science analyst Matilda explains what we could lose if the world's plants disappear, how we can save them and why we need to act now. → p22

DR HELEN SCALES
While making *Planet Earth III* scientists discovered something astounding on the bed of the Pacific Ocean. Marine biologist Helen explores more. → p46

DR EZZY PEARSON
BBC Sky at Night magazine's features editor looks into the projects that are recreating the lunar surface on Earth in order to test the next-generation of rovers. → p54

STEPHEN BAXTER
Acclaimed sci-fi author and science writer Stephen dives into the ideas *Doctor Who* thrives on. Think time travel and impossibly dimensioned phone boxes. → p70

ON THE BBC THIS MONTH...

Uncanny
This TV show, based on a BBC Sounds podcast, investigates people's real-life paranormal encounters. The show's presenter Danny Robins (below) talks to professional sceptics and believers alike, and asks the viewer to make up their own mind. It's a great watch if you love a ghost story or if you just want to argue with your partner's cognitive biases.
BBC Two, 9pm Fridays
Also available on BBC iPlayer

Planet Earth III
If you aren't watching this already, what are you doing? Yes, baby seals get eaten, but this series also looks at the impact humans are having on the planet and the incredible creatures we share it with.
BBC One, Sundays
Also available on BBC iPlayer

The Best Medicine
Comedy and science rarely work in combination. But this is a genuinely rare and brilliant fusion of the two. This panel show, fronted by Kiri Pritchard-McLean (above) explores the bizarre but profound history – and future – of medicine. It's funny, warm and thought-provoking, all at once. A rare gem.
BBC Radio 4
Also available on BBC sounds

CONTACT US

Advertising
David.DSouza@ourmedia.co.uk
0117 300 8110
Letters for publication
reply@sciencefocus.com
Editorial enquiries
editorialenquiries@sciencefocus.com
0117 300 8755
Subscriptions
buysubscriptions.com/contactus
03330 162113*
Other contacts
sciencefocus.com/contact

*UK calls will cost the same as other standard fixed line numbers (starting 01 or 02) and are included as part of any inclusive or free minutes allowances (if offered by your phone tariff). Outside of free call packages call charges from mobile phones will cost between 3p and 55p per minute. Lines are open Mon to Fri 9am–5pm. If calling from overseas, please call +44 1604 973721. *BBC Science Focus* (ISSN 0966-4270) (USPS 015-160) is published 14 times a year (monthly with a Summer issue in July and a New Year issue in December) by Our Media, Eagle House, Bristol, BS1 4ST. Distributed in the US by NPS Media Group, 2 Enterprise Drive, Suite 420, Shelton, CT 06484. Periodicals postage paid at Shelton, CT and additional mailing offices.
POSTMASTER: Send address changes to *BBC Science Focus*, PO Box 401 Williamsport, PA 17703.

CONTENTS

REGULARS

13 DISCOVERIES

Scientists have found a way to create lunar launchpads using Moon dust and sunlight.

30 REALITY CHECK

Sick days for UK workers are at their highest level for years. Find out why...

78 Q&A

FEATURES

37
INNOVATIONS
Sony's new WF-1000XM5 earbuds get tried and tested

28
DR MICHELLE GRIFFIN

"SO FAR, 90 WOMEN AROUND THE WORLD HAVE RECEIVED UTERINE TRANSPLANTS"

WANT MORE?

Don't forget that *BBC Science Focus* is available on all major digital platforms. We have versions for Android, as well as an iOS app for the iPad and iPhone.

Can't wait until next month to get your fix of science and tech? Our website is packed with news, features and Q&As to keep your brain satisfied.
sciencefocus.com

INSTANT GENIUS

Our bite-sized masterclass in podcast form. Find it wherever you listen to your podcasts.

LUNCHTIME GENIUS

A DAILY DOSE OF MENTAL REFRESHMENT DELIVERED STRAIGHT TO YOUR INBOX

Sign up to discover the latest news, views and breakthroughs from the *BBC Science Focus* team
sciencefocus.com/newsletter

EYE OPENER

A helping hand

LA PAZ, BOLIVIA

Meet Richard Vargas, a metal worker from La Paz, who lost his hands in a dynamite explosion six years ago. He also lost his job and suffered social discrimination as a result. But his fortunes changed, thanks to the work of Bolivian electro-mechanical engineer Antonio Riveros.

For the people of Bolivia, a country plagued by accidents involving explosives, prosthetic limbs are hard to come by. Most are made in Europe or North America and designed for white skin, but the biggest hurdle to getting them is cost – replacement limbs are often too expensive for the typical Bolivian.

In Bolivia, prosthetics can cost more than six years of minimum-wage salary. That's partly why Riveros founded Creotec, a prosthetics company catering to low-income Bolivians, with prices from as little as $300 (almost £250).

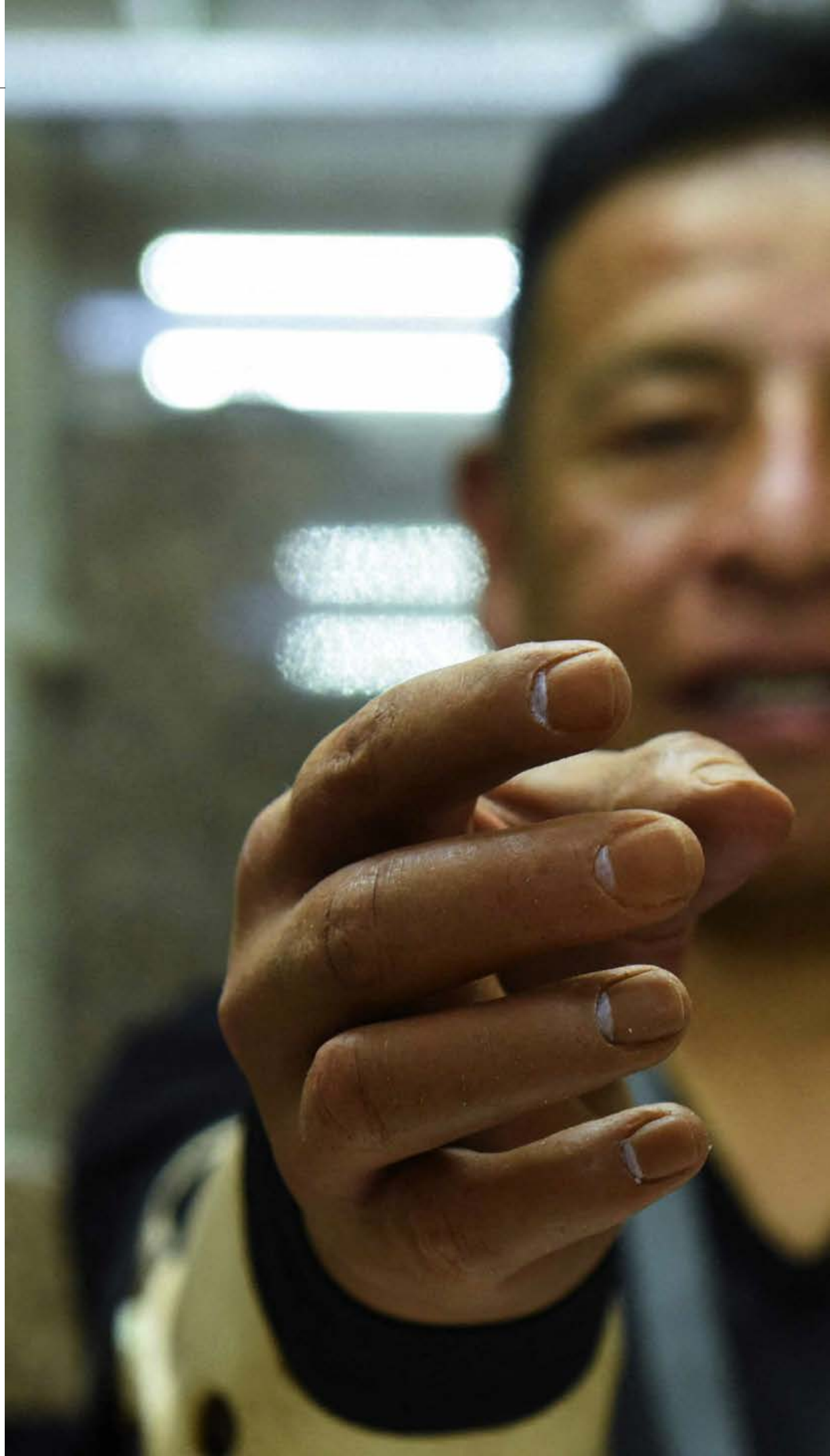
The artificial body parts are designed to match a patient's age and skin tone, and even feature wrinkles and tiny hairs. Vargas now wears two hyperealistic prosthetic hands, allowing him to write, eat and do many of the things he did before his accident.

REUTERS

VISIT US FOR MORE AMAZING IMAGES:

SCIENCEFOCUS

BBCSCIENCEFOCUS



EYE OPENER

Made it... Finally

MOUNT SHARP, MARS

After four attempts over three years, NASA's Curiosity rover has finally made it to the Gediz Vallis Ridge on Mars, seen here on the right of the image.

Although a ridge doesn't sound all that exciting, this one contains information from a remarkable period in the Red Planet's history.

Up until around three billion years ago, Mars was wet: vast oceans, rivers and lakes covered its surface, much like Earth today. During this time, torrents of water carried rocks and debris down Mount Sharp (Aeolis Mons), seen here on the far left. This huge muddy landslide solidified, before being chiselled away by Martian winds to form the Gediz Valley Ridge we see today. In other words, it's a record of one of the last wet periods seen on Mars.

Getting here was so hard because the knife-sharp rocks and steep slopes have previously forced the rover to turn back. This image is made from 136 photos stitched together, and the colours adjusted to match how human eyes would see the landscape.

NASA/JPL

VISIT US FOR MORE AMAZING IMAGES:

SCIENCEFOCUS

BBCSCIENCEFOCUS

FEEDBACK

YOUR OPINIONS ON SCIENCE, TECHNOLOGY AND OUR MAGAZINE

reply@sciencefocus.com
BBC Science Focus, Eagle House, Bristol, BS1 4ST
@sciencefocus
www.facebook.com/sciencefocus
@bbcsciencefocus

LETTER OF THE MONTH

Faster than light?

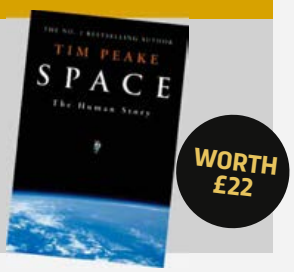
As ever, Marcus Chown writing for *BBC Science Focus* makes interesting reading, especially a paragraph midway through his feature 'Ghost Particles of the Milky Way' (October, p64), which states: "This results in a cascade of subatomic shrapnel, with some of the particles travelling through the ice faster than the speed of light." Does this mean we're seeing something that has broken the 'light barrier'?

Jeff Bourn, via email

Marcus Chown replies: In any medium, the speed of light is less than the speed of light in a vacuum (close to 300,000km per second), so there's always leeway for a particle to travel faster than the speed of light in the medium. The speed of light in a vacuum is the only speed that cannot be exceeded.

WRITE IN AND WIN!

The writer of next issue's *Letter of the Month* wins a copy of ***Space: The Human Story***, the new book by British astronaut Tim Peake. Put pen to paper (or fingertips to keyboard) and you could get your hands on this fascinating look into the lives of the men and women who shaped the first 60 years of space exploration.

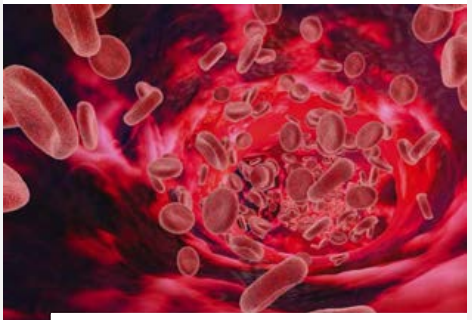


WORTH £22

Work together

I entirely agree with the view expressed by Peter Davey (October, p12) – space exploration must continue. If only we could develop an international consortium so nations could work together on it. Costs overall could be greatly reduced, while progress with research and development, on many fronts, would no doubt be much improved. The considerable resources this would save could go towards saving our planet and ensuring that all its inhabitants get the food, shelter and medical care they need. Just a pipe dream? Hopefully not.

Irene Wears, Middlesex



We may soon need more young blood donors

Blood relatives

Being in my late sixties, I was particularly interested in your news story on how young blood rejuvenates ageing brains (September, p16). But what the article didn't reveal was what volume of blood I would need to harvest from my grandchildren, or how frequent the transfusions should be. Once a year? Once a month? I sensed some reticence from my eldest grandson when I mentioned it to him, so I wondered whether it might be possible to manufacture the platelets artificially?

Terry Loades, via email

Other factors at play

While I found Prof Michael Kelly's article on 20mph speed limits in Edinburgh interesting (September, p36), I'm not convinced by his

"ANOTHER THING YOU CAN TRY IS GRAVITY OFF-SET. IT'S WHERE YOU USE A CRANE OR, IF IT'S A SMALL ROVER, A LARGE HELIUM BALLOON... HAVE YOU SEEN THE MOVIE UP*?"*

DR TERRY FONG, p54

There could be other reasons why 20mph speed limits introduced in Edinburgh reduced road accidents

NICOLE R FULLER/NSF, GETTY IMAGES, ALAMY

assertion that the reduction in road accidents is entirely a consequence of the introduction of a 20mph restriction.

I don't have access to Prof Kelly's statistics, however, the picture he paints is somewhat one-sided. Firstly, "80 per cent of Edinburgh's streets" have been given a 20mph speed limit, but aren't these roads almost entirely within housing estates?

The condition of these roads (potholes, speed bumps, chicanes and so on) combined with the number of vehicles parked on them, makes it almost impossible to drive at more than 20mph. There are also distributor roads where bollards are used to provide cycle lanes. These reduce the road width to a single lane, so we all have to drive at the speed of the slowest vehicle. My car's computer recorded an average speed of 17-18mph for town driving *before* the introduction of the 20mph limit.

What's more, the lack of an expected 'push back' from commercial vehicle drivers, buses and taxi drivers (as well as many non-commercial drivers) is easily explained: the 20mph limit is simply ignored!

Bill Little, via email

Gulp, gulp... and gone

[Like Ramona Cronin (October, p12),] I also have a cure for hiccups: try to drink half a glass of cold, still water taking the smallest possible sips, swallowing after each one. Then, drink the rest of the cup in one go. After that your throat should be reset to normal. It works every time for my family.

Bonkeith Oum, via email

THE TEAM

EDITORIAL
Editor & brand lead Daniel Bennett
Managing editor Robert Banino
Commissioning editor Jason Goodyer
Digital editor Thomas Ling
News editor Noa Leach
Staff writers Alex Hughes, Holly Spanner

ART
Art editor Joe Eden
Picture & asset manager James Cutmore

CONTRIBUTORS
Amy Arthur, Ramon Avelino, Louise Banbury, Stephen Baxter, Hayley Bennett, Peter Bentley, Dean Burnett, Jon Butterworth, Michelle Griffin, Alastair Gunn, Matthew Holland, Christian Jarrett, Pete Lawrence, Bernard Leonardo, Katie Mack, Rosanna Morris, Panagis Matsangouras, Stephanie Organ, Ezzy Pearson, Ceri Perkins, Helen Pilcher, Andy Ridgway, James Round, Helen Scales, Ian Taylor, Luis Villazon, Joe Waldron, Chiara Xie, and all the folks at VMG Digital.

ADVERTISING & MARKETING
Business development manager David D'Souza
Newstrade manager John Lawton
Subscriptions director Jacky Perales-Morris
Direct marketing manager Kellie Lane

TECHNOLOGY
Senior Marketing Manager – Digital Editions Kevin Slaughter
Tech director Azir Razzak

INSERTS
Laurence Robertson 00353 876 902208

LICENSING & SYNDICATION
Director of International, Licensing & Top Gear Magazine, UK Tim Hudson
Head of Partners, Brand Management & Ethical Compliance Molly Hope-Seton
Head of Licensing Tom Shaw
Head of Syndication Richard Bentley

PRODUCTION
Production director Sarah Powell
Production coordinator Hannah Gazzard
Ad services manager Paul Thornton
Ad designer Camilla Owen

PUBLISHING
Publisher Andrew Davies
Group managing director Andy Marshall
CEO Tom Bureau

BBC STUDIOS, UK PUBLISHING
Chair, editorial review boards Nicholas Brett
Managing director, consumer products and licensing Stephen Davies
Global director, magazines Mandy Thwaites
Compliance manager Cameron McEwan
UK.Publishing@bbc.com
www.bbcstudios.com

EDITORIAL COMPLAINTS
editorialcomplaints@immediate.co.uk

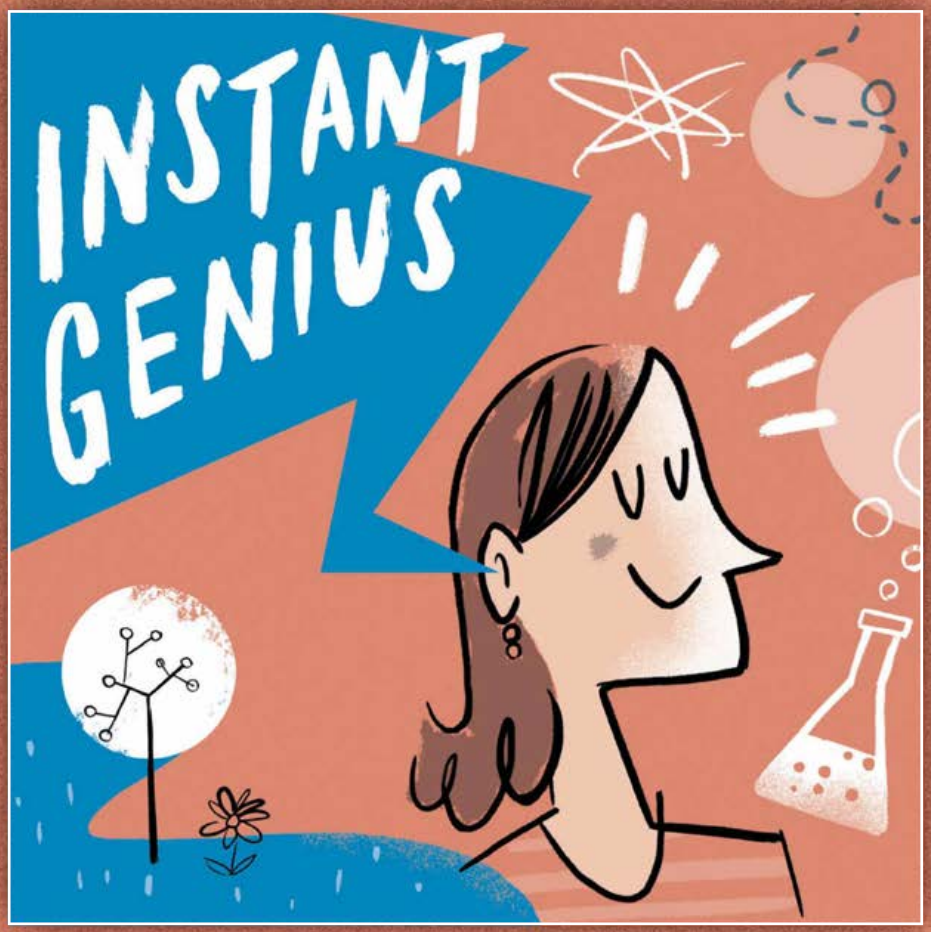
ANNUAL SUBSCRIPTION RATES (INC P&P):
UK/BFPO £83.86; Europe & Eire €114;
Rest of World $137

Audit Bureau of Circulations 70, 284 (combined, Jan-Dec 2022)

BBC Science Focus Magazine is published by Our Media Ltd (an Immediate Group Company), under licence from BBC Studios who help fund new BBC programmes.

DON'T JUST READ THIS MAGAZINE... LISTEN TO IT TOO

Discover the podcast from the team behind *BBC Science Focus*, available on Spotify, Apple Podcasts, Google Podcasts and Amazon Music
sciencefocus.com/instant-genius-podcast



FEATURING

CAT PSYCHOLOGY
with
Dr Zazie Todd

MASS EXTINCTIONS
with
Prof Michael Benton

THE UNIVERSE
with
Dr Neil deGrasse Tyson

OCEAN CURRENTS
with
Dr Helen Czerski

BAD MONKEY PHOTOGRAPHY

"A world without plants and fungi is a world without humans. Plants underpin all aspects of humanity"
Dr Matilda Brown **p22**

DISCOVERIES

PHYSICS

BRIGHT LIGHTS

Coherent light produced in a small space has the potential to change... everything **p14**

NEUROSCIENCE

IGNORE YOUR ALARM

Hitting the snooze button may benefit your brain function **p16**

SPACE

ONE FOR THE ROAD

Scientists have come up with a way to build roads on the Moon, using lasers and lunar dust **p17**

NEUROSCIENCE

WHAT'S IN YOUR HEAD

New map of the cells in your brain shows how complex your grey matter really is **p18**

ASTRONOMY

CRASH FLASH

Mysterious blazing light in space may have been caused by planetary collision **p19**

ASTRONOMY

RING OF FIRE

Recent annular eclipse casts shadow over much of America **p20**

PRIMER

PLANTS IN PERIL

The known and unknown species of the planet's flora are facing extinction **p22**

'Paved' roads on the Moon could help minimise the threat abrasive lunar dust poses to equipment

PAVER CONSORTIUM

PHYSICS

ULTRA-BRIGHT LIGHT BREAKTHROUGH COULD CHANGE EVERYTHING

Creating an ultra-bright light in a small space is harder than it sounds... But scientists think it may be possible

A new method of producing an ultra-bright light that breaks traditional laws of particle physics, could potentially spark a technological revolution. The ultra-bright light, a form of 'coherent light', is created by particles moving in synchrony rather than independently. This synchrony creates incredibly fast, intense pulses that operate on a scale of atto-seconds – or one thousandth of a millionth of a billionth of a second.

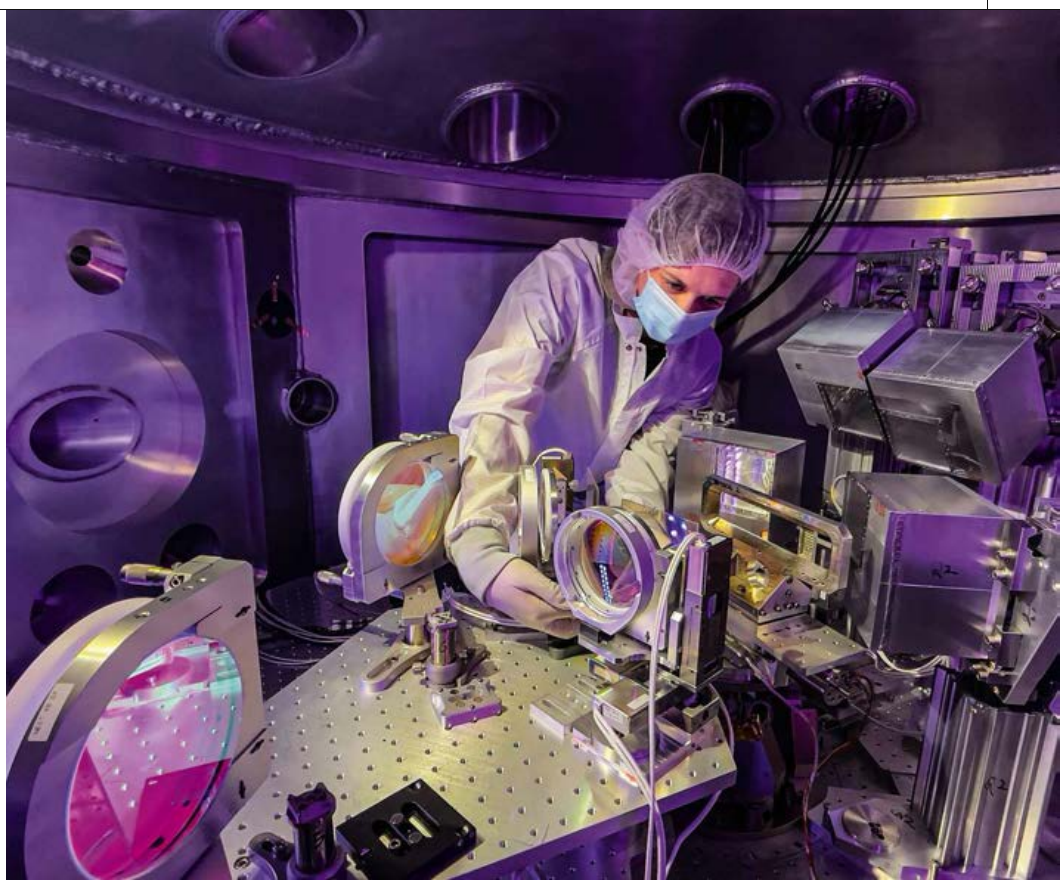
While machines that are currently capable of creating ultra-bright light are miles long, scientists have now produced plans for just such a light source that can fit into a single room. It could lead to a "mini-societal, technological and scientific revolution", the researchers behind the development told *BBC Science Focus*.

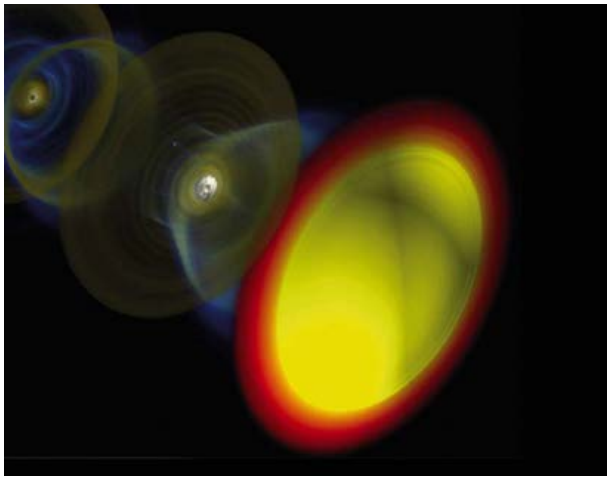
In a move set to radically improve global healthcare and future technology, the new ultra-bright light machine could make X-rays and radiotherapy treatments cheaper in future, and enable the creation of powerful computer chips. It could even create ultra-bright light that can probe the dense matter of stars and planets, deepening our understanding of cosmic behaviour, according to researchers.

The new discovery is part of a global effort to make ultra-bright light sources broadly available; the Nobel Prize in Physics this year was awarded to scientists who produced atto-second light beams. The researchers behind this new study, published in the journal *Nature Photonics*, aim to do the same, but using a much more compact machine. They say that this would mark the beginning of widespread technological and scientific advances across the world.

Normal light sources, for example lightbulbs or the Sun, produce a white light in which photons move independently. This 'incoherent light' is like "a loosely tuned radio, where we mostly hear static noise," according to the study's authors. By comparison, the synchronised photons in coherent light are more like a "finely tuned orchestra".

JACQUELINE RAMSEYER ORRELL/SLAC NATIONAL ACCELERATOR LABORATORY X2, BERNARDO MALACA





CLOCKWISE FROM LEFT The Linac Coherent Light Source (LCLS) laser at the SLAC National Accelerator Lab in the US can produce ultra-bright light but is 3km (1.9 miles) long; Project scientist Chandra Curry works on one part of the LCLS laser; Computer simulations of quasiparticles have led scientists to think they can be used to create powerful ultra-bright light sources using much smaller machines than those currently in use

"The synchronised photons in coherent light are more like a 'finely tuned orchestra'"

In the study, the scientists used advanced computer simulations to measure the unique properties of quasiparticles formed by groups of electrons moving in synchrony. Quasiparticles are created by a collection of particles acting together in a way that enables them to be treated like a single particle.

This class of particles exhibits a number of intriguing properties: it can theoretically move at any speed (even faster than the speed of light) and can withstand the powerful forces that surround a black hole.

The authors compare the motion of the quasiparticles in their experiment to a Mexican wave: the wave can travel around a stadium faster than any individual could, but each individual participant stays in the same place.

Similarly, the scientists observed each individual electron making simple movements. But when they joined together, the collective motion combined to create an electron Mexican wave that can move faster than light. The whole system forms a quasiparticle that can be thought of as a single electron capable of emitting highly synchronised photons, and thus extremely bright light.

We shouldn't get carried away, though, suggests Marcus Chown. Commenting on the study he was not involved with, the award-winning science writer said: "If this quasiparticle approach can indeed put a source of ultra-bright, ultra-short pulses of light on a tabletop, it will revolutionise science. However, it should be emphasised that, so far, this is only a theoretical possibility."

NEUROSCIENCE

HITTING THE SNOOZE BUTTON MAY BOOST BRAIN FUNCTION

Good news for snoozers: new research reveals that if you snooze, you *don't* lose

You can stop feeling guilty for snoozing your alarm: a new study by scientists in Sweden suggests that hitting snooze may actually help you become more alert after finally waking.

The research, published in the *Journal of Sleep Research*, involved two studies. The first established the general profile of the 1,732 adults who participated: 69 per cent of whom confirmed they used the snooze function on their alarms.

The snoozers tended to be younger than non-snoozers; they also had later chronotypes, meaning their natural sleep/wake pattern made them 'night owls', rather than 'morning larks'. Snoozers were also more likely to sleep for a shorter amount of time and to experience morning drowsiness.

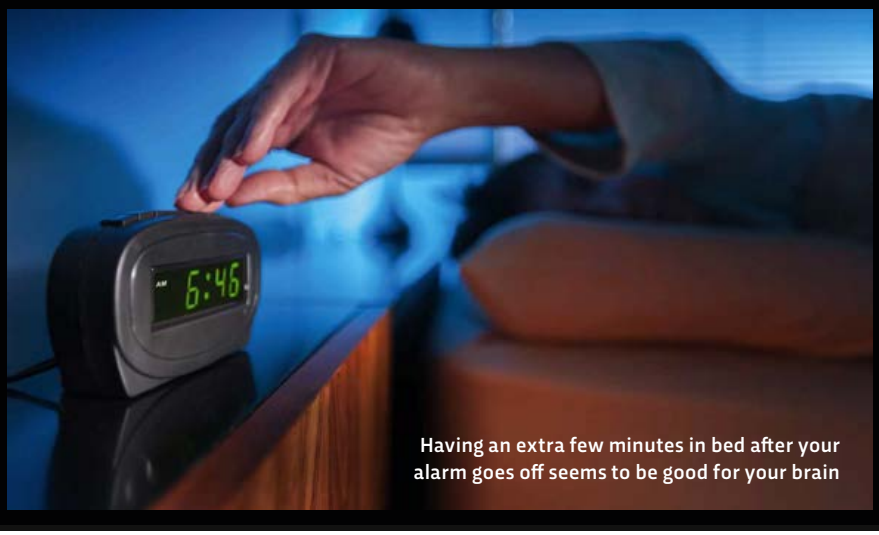
Only regular snoozers were examined in the second study, which took place over two nights in a sleep lab. One morning, the participants were allowed to snooze for 30 minutes; the other, they were made to rise abruptly. They then had to perform arithmetic and memory tests as soon as they woke up and at various points throughout the day.

When participants were gifted an extra 30 minutes of snoozing, they performed better on most of the tests. The researchers believe this may be because snoozing allows you to reach a lighter sleep stage that's easier to wake up from than slow-wave/rapid eye movement sleep, which your first alarm is likely to catch you in.

The benefits of snoozing disappeared after 40 minutes, however. At this point, your performance on cognitive tasks won't be affected whether you snooze or wake up immediately, the study suggests.

As the study highlights, snoozing generally shortens total sleep time, compared to setting your alarm later and waking up instantly. Nevertheless, the study found that snoozing had no clear impact – positive or negative – on stress hormone levels, mood, morning drowsiness or overnight sleep quality.

"The findings indicate that there's no reason to stop snoozing if you enjoy it, at least not for snooze times of around 30 minutes," said Dr Tina Sundelin, one of the study's authors. "In fact, it may even help those with morning drowsiness to be slightly more awake once they get up."



Having an extra few minutes in bed after your alarm goes off seems to be good for your brain

PAVER CONSORTIUM X4, GETTY IMAGES

SPACE

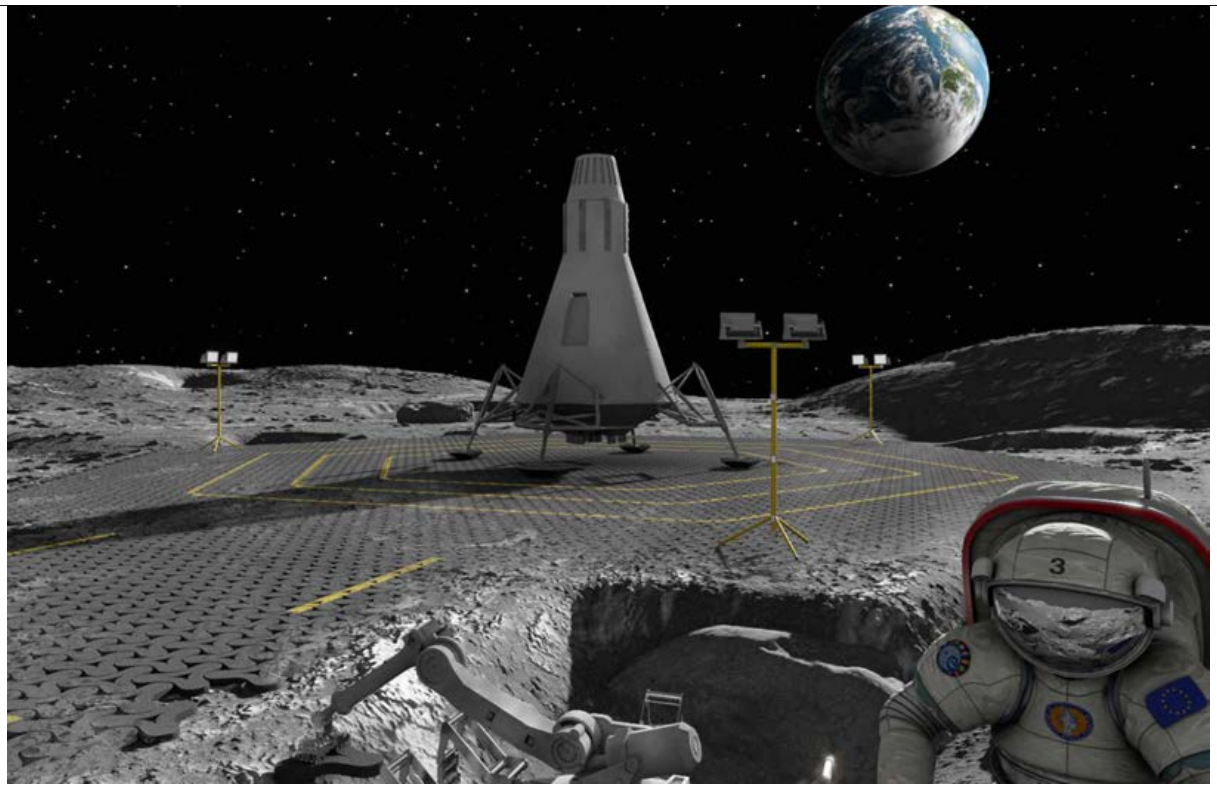
SCIENTISTS PLAN TO MELT MOON DUST TO LAY LUNAR ROADS

Triangular 'paving stones' could be made on the Moon using the Sun's rays and might solve the problems caused by Moon dust

Any human feat of exploration usually requires roads at some point, and that applies even on the Moon. But how can we build lunar roads? By using sunlight and the Moon's dust, which up until now has presented a problem for lunar explorers and equipment.

The low levels of gravity on the Moon means that any movement on its surface kicks up dust, which can take hours to settle. This dust is ultra-fine and abrasive enough to damage equipment if it gets inside it (lunar dust eroded the Apollo missions' spacesuits).

For transport systems on the Moon to be successful, solid roads and landing pads will be essential. But sending road-building materials to the lunar surface is expensive. So



CLOCKWISE FROM TOP LEFT The triangular 'paving stones' interlock to create solid surfaces; how the roads could look; a single melt layer is approximately 2cm deep; melting simulant Moon dust using a carbon-dioxode laser beam

researchers at Aalen University, Germany, have discovered that by melting Moon dust they can create solid, robust slabs that holds this extremely fine dust in place.

These slabs will make it easier for rovers to travel across the Moon's surface, but also reduce soil dislodged by rocket thrusters from vehicles landing and launching.

For the study, published in *Scientific Reports*, the researchers used a Moon dust substitute called EAC-1A, which the European Space Agency developed for this type of testing.

The researchers, working on Earth, melted the EAC-1A using a carbon dioxide laser. On the Moon, this laser will be replaced with focused solar radiation: a giant lens of 2.37m^2 (25.5ft^2) will concentrate sunlight to melt Moon dust into 20cm-wide triangular slabs to make paving stones.

"A giant lens will concentrate sunlight to melt Moon dust into paving stones"

"We were able to consolidate material up to a depth of more than 20mm, which is quite massive," Prof Jens Günster, the study's corresponding author, told *BBC Science Focus*. "We were very happy with the mechanical properties of the consolidated material."

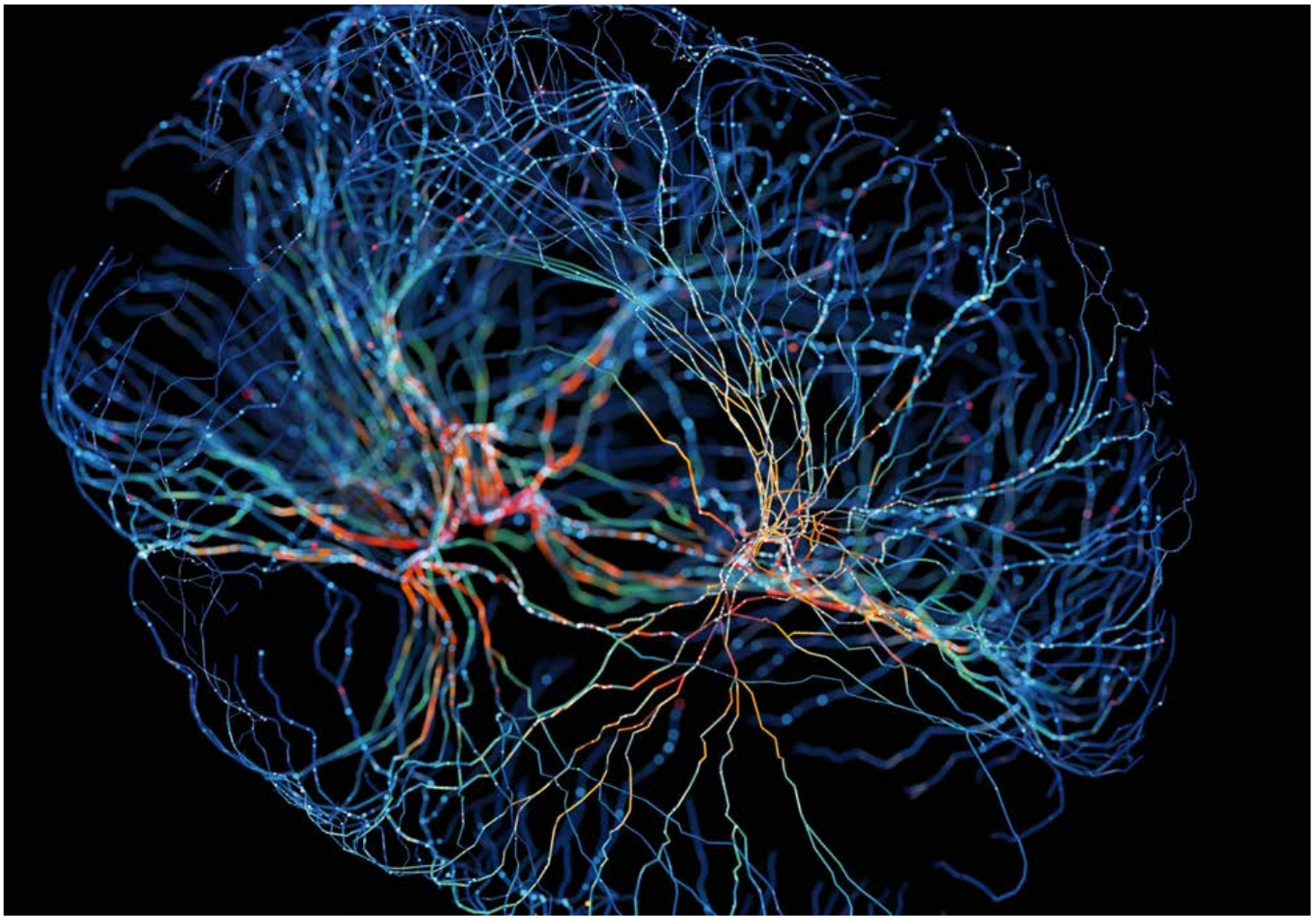
Once the solar lens is sent to the Moon, the road-building process will only use lunar resources.

Further research is required to refine the process before it's capable of being reproduced on the Moon. Günster believes it could be possible within the next decade, however – in time for missions such as those in NASA's Artemis programme, which includes plans for the first crewed Moon landing since Apollo 17 in 1972, and for Gateway, a new space station that will be built in orbit around the Moon.

NEUROSCIENCE

A MAP OF THE BRAIN CELLS THAT MAKE US UNIQUE MARKS "A PIVOTAL MOMENT IN NEUROSCIENCE"

Benchmark study maps over 3,000 cell types in the human brain



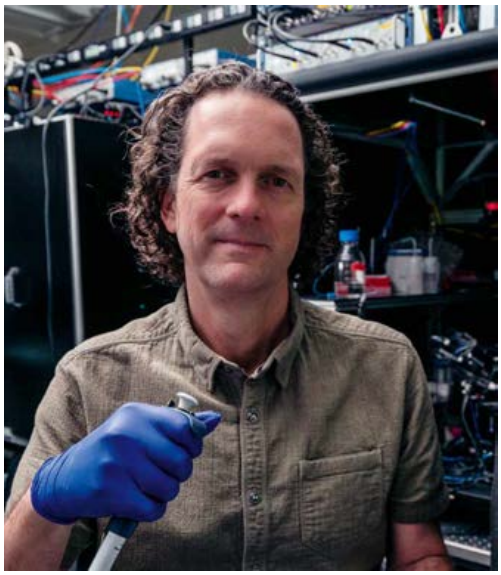
Scientists have long puzzled over the vast complexity of the human brain. Now, researchers from around the world have mapped its cellular makeup and discovered that there are over 3,000 cell types in the human brain, including hundreds they didn't know existed.

Speaking to *BBC Science Focus*, Dr Ed Lein, senior investigator and neuroscientist at the Allen Institute for Brain Science in Seattle, said: "The brain is an astonishingly complex cellular organ… and we can now really define and map these cell types across it." Previous studies had only mapped the brain cell types of particular regions in the cortex (the outermost part of the brain). These studies found over 100 different brain cell types. The new research has expanded that mapping to almost 100 regions across the entire human brain – and found *thousands* of different brain cells.

"The researchers were surprised to discover that even the oldest parts of the brain (in evolutionary terms), are highly complex"

For many parts of the brain, no one has ever seen this level of complexity and variety until now. The researchers were surprised to discover that even the oldest parts of the brain (in evolutionary terms),

GETTY IMAGES, ERIK DINNEL/ALLEN INSTITUTE, MARK GARLICK



Dr Ed Lein, senior investigator and neuroscientist

which were previously thought to be very simple, are in fact highly complex.

In the study, scientists at the Allen Institute used a technique known as single-cell transcriptomics, which involves studying all the genes switched on in individual brain cell's DNA. They analysed post-mortem tissues from brains donated to science, and healthy living tissue donated by brain surgery patients.

The study is part of a huge project to catalogue the size and complexity of the human brain, and was one of a suite of 21 papers released simultaneously in the journals *Science*, *Science Advances* and *Science Translational Medicine*.

One of the other studies, also led by the Allen Institute, found that the connections between the 3,000 brain cell types are crucial to making each of us unique. Although "we all share a common blueprint and set of building blocks," said Lein, there is "variation in how those blocks are put together and the properties of those blocks that make us unique as individuals."

In a press release, Lein described the joint discoveries as "a pivotal moment in neuroscience". The findings will help to create more comprehensive atlases of the human brain, as well as brains of other primates. These could improve our understanding of brain diseases and disorders, and our ability to treat them.

"This is very much like the early stages of the Human Genome Project," Lein added in conversation with *BBC Science Focus*. "We have now begun that journey."

ASTRONOMY

MYSTERIOUS AFTERGLOW POTENTIALLY CAUSED BY MASSIVE COLLISION OF PLANETS

Scientists have a probable cause for the unexplained brightness

A peculiar blaze of light, which has stumped researchers for over four years, was likely produced by the collision of two ice giant exoplanets, according to a new study.

These planets could have been similar in size to Neptune and Uranus – the ice giants in our Solar System – according to the study published in *Nature*.

An initial observation by an astronomy enthusiast saw the brightness double around a Sun-like star approximately 1,800 light-years from Earth. The brightness began to fade three years later.

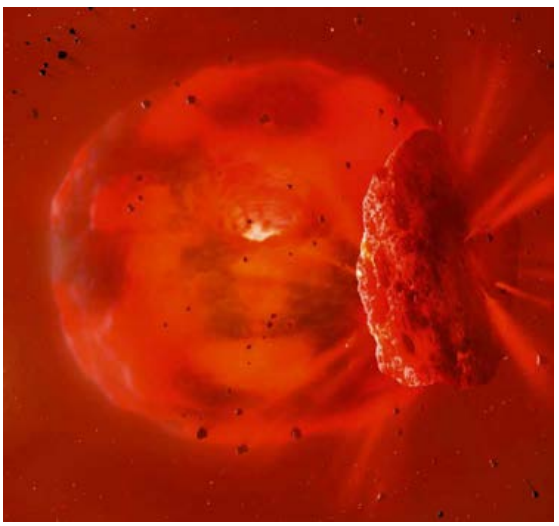
"To be honest, this observation was a complete surprise to me," said co-lead author Dr Matthew Kenworthy, an associate professor at Leiden University in The Netherlands. "An astronomer on social media pointed out that the star brightened up in the infrared over 1,000 days before the optical fading. I knew then this was an unusual event."

The afterglow was detected by NASA's NEOWISE (Near-Earth Object Wide-Field Infrared Survey Explorer) mission – a space telescope that searches for asteroids and comets. Then, using computer models based on the temperature and size of the glowing material, scientists theorised possible causes. The most likely being the glow was caused by two ice giants colliding. If this turns out to be is correct, the dimming of the intense light would have been caused by a dust cloud moving in front of the star.

Over the coming years, Earth- and space-based telescopes will make further observations. These may spot a cloud of dust spreading over the collision site, which the telescopes would pick up as a scattering of light. This cloud is a result of the collision sending fragments of rock and ice flying around the star, creating a glowing planetary body.

In the future, the researchers say that this circling material may condense to also form a string of moons that will orbit the new planet.

"This sighting offers our first real-time glimpse into the workings of giant impacts, collisions between planets, and how systems evolve afterwards," co-lead author Dr Simon Lock, a research fellow at the University of Bristol, told *BBC Science Focus*. "In effect, we'll be able to watch the final stages of the birth of a planet."



ASTRONOMY

THE BURNING 'RING OF FIRE' ECLIPSE... THAT WENT DOWN, DOWN, DOWN THE AMERICAS

The burning ring produced by the Sun and Moon crossing paths won't be seen again in the US until 2039

On 14 October 2023, a spectacular annular eclipse cut across parts of North, Central and South America. Millions of people watched the 'ring of fire' as it burned across the sky.

The ring travelled over eight US states, Mexico and Panama, then crossed into Brazil before heading out over the Atlantic Ocean. The whole event took place over 2.5 hours, with the annular eclipse lasting only 4-5 minutes in the middle of the astronomical phenomenon.

An annular eclipse occurs when the Moon passes in front of the Sun, but when the Moon's elliptical orbit hasn't brought it close enough to Earth to completely block out the star. As a result, a small fiery halo of sunlight, known as the 'annulus', remains visible.

Annular solar eclipses are uncommon: the next one in the US won't occur until 2039 and will only be visible in parts of Alaska. The next European annular eclipse will take place in 2028, but the UK will only see a partial eclipse.

As well as teaching astrophysicists about the Sun, solar eclipses have also helped to prove Einstein's theory of General Relativity. The striking natural phenomenon also allows scientists to study the ionosphere (the upper part of our atmosphere) and how it affects communications and space weather.

1

3

1. The 'Ring of Fire' effect caused during the annular solar eclipse, as seen from Penonome, Panama. Here, the Moon is directly in front of the Sun. At the maximum of the eclipse, the Moon covered approximately 70 per cent of the Sun's disc.

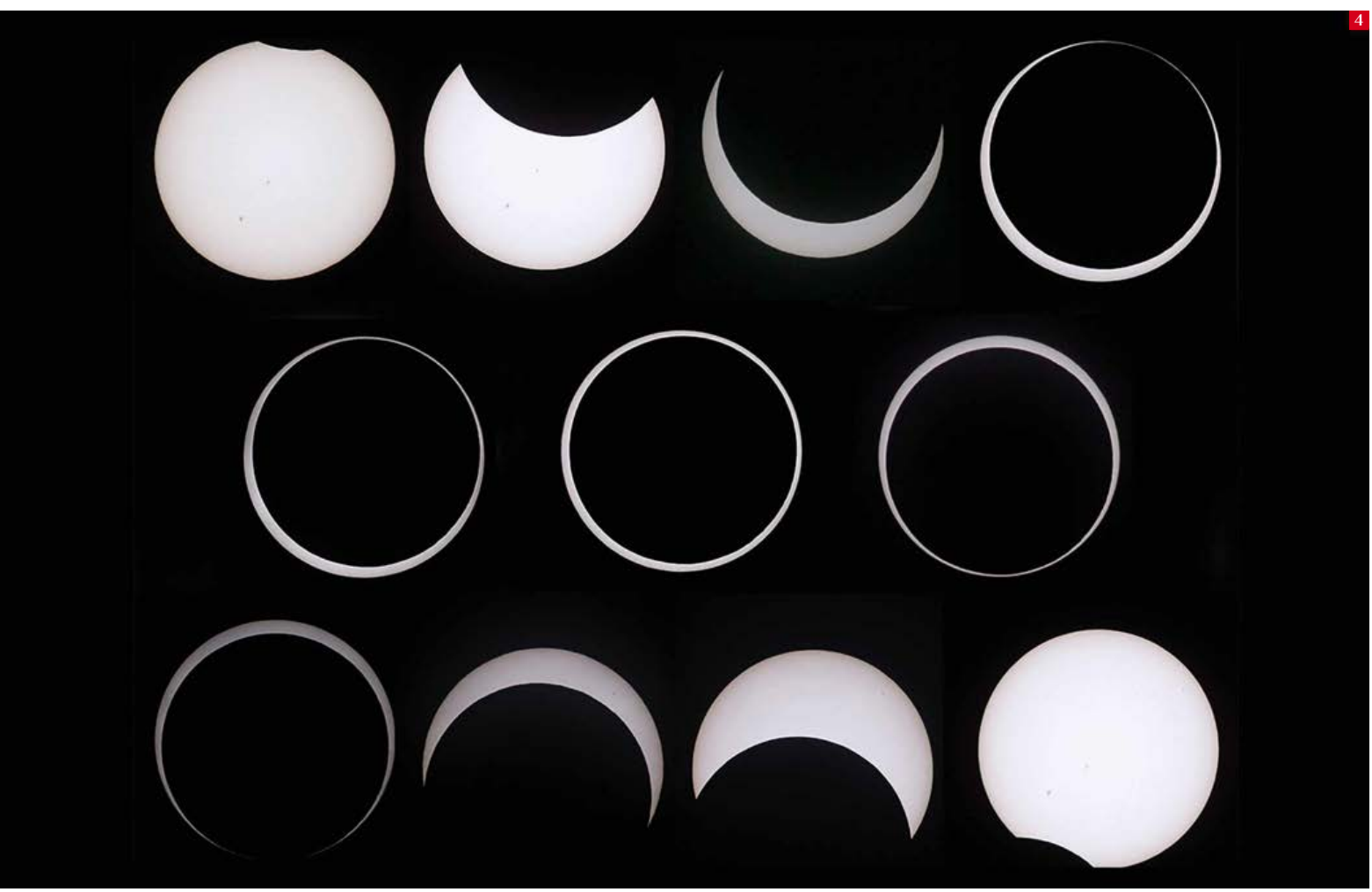
2. NASA's Earth Polychromatic Imaging Camera (EPIC) captures the annular eclipse from space as the Moon casts a shadow over America and Mexico. EPIC's viewpoint lies about 1.5 million kilometers away from Earth, aboard the Deep Space Climate Observatory (DSCOVR) satellite, which monitors space weather. There were limited viewing points from Earth: at its widest point, the path of annularity measured 220km (137 miles), while at its narrowest was 190km (118 miles) wide.

3. People watch the annular solar eclipse at the Luis Enrique Erro Planetarium of the National Polytechnic Institute in Mexico City. Though they're bathed in the shadow cast by the Moon, special, purpose-made eclipse glasses are still needed to protect their eyes from the Sun's light – even though the Moon is obscuring all but a thin sliver of it. Solar retinopathy can occur when intense light energy (in this case, from the Sun) damages the cells in the retina.

4. A compilation of photographs shows the progress of the annular solar eclipse on 14 October 2023 as it passed over Capitol Reef National Park, Utah, USA.

GETTY IMAGES X3, NASA

2



4

PRIMER

PLANT APOCALYPSE

The race is on to document and protect the world's plant and fungi species... and everything is at stake if we lose

In the 19th century, Charles Darwin dreamed of a list which would describe all of the world's known plants and where they could be found. This October, the Royal Botanic Gardens at Kew fulfilled that dream by publishing what has been described as the most comprehensive plant database ever produced.

But the world has changed since Darwin dreamed up the idea. Hence the report, named the *State of the World's Plants and Fungi 2023*, not only details the discoveries of over 18,000 new plant and fungi species since 2020, but also the incredible level of extinction risk they face.

Over 200 scientists from 30 countries were involved in producing the 60,000 peer-reviewed species conservation assessments that underpin the report. We spoke to one of those scientists – Dr Matilda Brown, conservation science analyst at Royal Botanical Gardens Kew – to learn more about it.

WHAT DID THE REPORT FIND?

The report provides a global health check on the world's plants and fungi, and it comes down to two big numbers.

First, using new modelling, we found that 45 per cent of all flowering plants are threatened with extinction. And second: we found that, of the species we have yet to describe (in a formal scientific paper), in the next years and decades over three quarters – 77 per cent – are already threatened with extinction. For fungi, it's harder to get that big picture of extinction risk, because we've only described around 10 per cent of fungal species. And of those, less than one per cent have conservation assessments [papers that detail how at risk they are].

WHAT COULD WE LOSE?

A world without plants and fungi is a world without humans. Plants underpin all aspects of humanity: they're what we eat, what we wear, what we get our medicines from.

Nine out of ten of our medicines come from plants, including the medicines we use to treat leukaemia, which come from the Madagascar periwinkle (*Catharanthus roseus*).

They're also responsible for the air that we breathe.

When we're talking about losing this amount of plant diversity, we're talking about losing an enormous amount of potential future opportunities.

For example, a species called *Vepris onanae* was only described as recently as 2022, but we're already looking at its potential anti-microbial properties. It's a medium-sized citrus tree found in the cloud forests of Cameroon, but it's already threatened. Species we're only just finding out about have the potential for untapped benefits to humanity.

There are potent medicinal uses of fungi, too, from penicillin to cholesterol medication. And we're just starting to explore some of its other uses, like as a building material and even as a bioremediator [microorganisms that break down contaminants] because we know that some fungi can actually digest plastics. It's a really exciting frontier of science.

WHAT WOULD A WORLD WITHOUT PLANTS AND FUNGI ACTUALLY LOOK LIKE?

That would depend on how we're losing these species. If we're talking about a climatic apocalypse with huge drought events, large portions of the world might become uninhabitable for most plants. But if we're looking at habitat loss and then regeneration, we'll probably see more weedy species taking their place.

Each species represents some amount of time of unique evolutionary history, anywhere up to a hundred million years. That's irreplaceable – we can't replicate tens of millions of years of evolution to bring them back and we shouldn't be losing species just because they're not important to us.

Eventually, replenishing lost biodiversity through natural evolution and new species would happen, but it's not going to help us as humans.

RBG KEW, XANDER VAN DER BURGT/RBG KEW, ALEX ANTONELLI/RBG KEW, BART WURSTEN

The *Victoria boliviana* species of lilypad was only discovered in 2022

Rainforests, home to many undiscovered species of plant and fungi are being cleared for agriculture

There are probably many new species of flora yet to be found in Brazil's Atlantic rainforest

Marsdenia chiridensis is a new species, discovered after 2020

"We know that if we want to bend the curve of biodiversity loss, we need to act now"

THIS IS A SERIOUS LEVEL OF THREAT. WHAT'S CAUSED IT?

The biggest threat to plants is habitat loss – or, at least, it's the biggest and most immediate *documented* threat. It's something that we can look at on satellite imagery; we can see that the land has changed from intact rainforest to become agricultural land.

There are other threats like over-collection of useful species, and climate change is certainly on the horizon. But it's a lot harder to document because, to get an estimate of climate change, we must have enough information about a species to be able to look at it under different climate scenarios and determine what proportion of its range will be lost. It's just not possible to look at each species individually when there are about a third of a million species to model. We're certainly worried about climate change, but it's a lot harder to put a number on it.

HOW FAR DOWN THE LINE ARE WE? IS THERE TIME FOR US TO FIX IT AND HOW CAN WE DO SO?

Given that documenting plant extinction risk is difficult, we're still working on a timeframe. We know that extinctions are double the rate that they were before 1900. But narrowing it down to when an individual species might go extinct is harder than you might think.

So what we're looking at currently is more of a threat level than a prediction. It's also both a warning and a prioritisation tool: it tells us, if we do nothing, which species are most likely to go extinct first, versus those that are likely to be able to hang on.

We know that if we want to bend the curve of biodiversity loss, we need to act now. There are some things that we know we've already lost that we won't be able to get back. But that doesn't mean that we shouldn't be acting now to preserve as much biodiversity as we can.

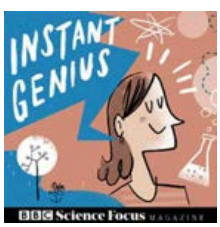
Preserving ecosystems is the best way to maximise that biodiversity into the future, because that protects all the species within it – including those that we know about, as well as the ones we haven't yet found.

DR MATILDA BROWN
Matilda is a conservation science analyst at the Royal Botanical gardens Kew.

DISCOVER MORE

LISTEN

For the full interview, listen on Instant Genius: ***sciencefocus.com/instant-genius-podcast***



COMMENT

DID THE JAMES WEBB SPACE TELESCOPE JUST SPOT GALAXIES THAT SHOULDN'T EXIST?

Given the age of the Universe, the galaxies we've just been shown appear to be too old. So, what's gone wrong?

If you've ever looked over at a shockingly productive colleague and asked, "How do you find the time?", then you'll know how cosmologists are currently feeling about the early Universe.

Since it started sending back data in mid-2022, the internationally funded, state-of-the-art James Webb Space Telescope (JWST) has been giving us images of distant galaxies that appear to have formed and matured far earlier than our models predicted.

Researchers have likened the situation to flipping through someone's family photo album expecting to find baby pictures and seeing a full-grown adult instead. With a person, you might just conclude that they're older than you thought. But with early galaxies, you quickly run into a problem with the age of the Universe.

JWST is looking at galaxies that are so distant that their light has taken more than 13 billion years to reach us. If the Universe is, as we currently think, 13.7 billion years old, there wouldn't have been enough time for such massive galaxies to have formed.

Headlines have been calling this a crisis for cosmology and a threat to the Big Bang theory. But before we throw out all our cosmology textbooks, let's dig a little deeper into the data.

As amazing as JWST is, the information it provides about the earliest galaxies isn't completely straightforward. While it has shown us spectacularly breathtaking views of nearby nebulae, star clusters and galaxies, its images of the most distant galaxies look, in general, like fuzzy little dots.

For the most part, the useful information we get from these images is actually from the spectrum of light they show – specifically, how much light is arriving at different colours (or wavelengths).

DR KATIE MACK

(@AstroKatie)

Katie is a theoretical astrophysicist. She currently holds the position of Hawking Chair in Cosmology and Science Communication at the Perimeter Institute for Theoretical Physics.

"That would mean we have to completely rethink cosmic evolution"

There are two ways that JWST can examine a light source. It can take a spectrum by spreading out the light with a spectrograph (which works a bit like a prism) and examining the brightness at each colour, or it can use filters that block all but a select range of colours.

In both cases, to determine properties such as the galaxy's age or the total mass of its stars, we compare the data to simulations of the spectrum we expect for a galaxy with those properties.

These measurements are also how we determine the galaxy's 'redshift', which tells us what moment in the Universe's history we're looking at. The galaxies we've seen with the highest redshift values are sending us their light from within the first 400 million years after the Big Bang.

It's here that we run into a problem. Based on model spectrum comparisons, many of these galaxies seem to have too many stars, or stars that are too old, for the time in which they've existed. But there are several ways we could be mistaken – some observational and some theoretical.

On the observational side of things, photometric measurements can sometimes be inaccurate; a few apparently high-redshift galaxies turned out to be much closer to us when we took spectra. There have also been telescope calibration issues (although they're likely all settled now).

Then there's the fact that we're only seeing very small patches of the sky: we could have stumbled onto a clump of galaxies that simply aren't representative of the norm.

On the theory side, there's even more uncertainty. Our models of galaxy spectra are based on much closer galaxies. What if the early galaxies had different populations of stars (more massive stars and fewer small ones, for instance)?

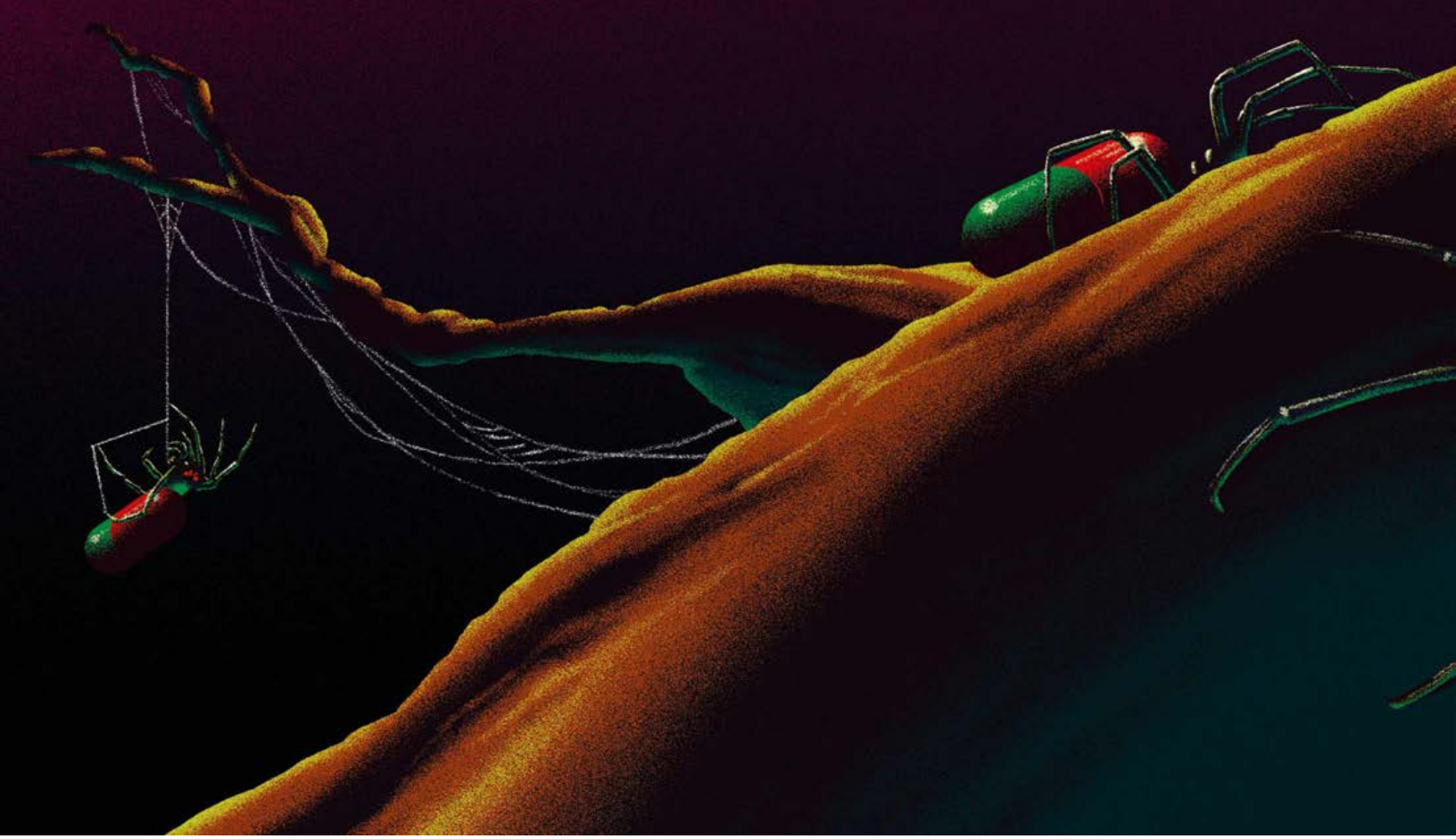
What if star formation happened more rapidly in the past due to different physical conditions, or varied substantially over time? We're already seeing hints that our models need adjusting based on weird balances of chemicals in the spectra.

The most exciting conclusion, of course, is that those galaxies really are super massive and couldn't have formed in the time allotted. That would mean we have to completely rethink cosmic evolution.

But the more conservative position is that both the theory and observations are too uncertain for solid conclusions just yet. Perhaps when we figure out which knobs to turn in our galaxy formation models, we'll find new insights into the formation of structure in the Universe.

Based on what we know now, it's plausible that the Universe formed its galaxies as soon as it could, but still within physical feasibility. Just like your amazingly productive officemate – what looks impossible to us might be less about altering the laws of physics and more about using the time we have more efficiently.

ILLUSTRATION: MATTHEW HOLLAND



COMMENT

SAYING NO TO DRUGS CAN BE HARD, ESPECIALLY WHEN OUR BRAINS HAVE EVOLVED TO SAY 'WHY NOT?'

The 'Stoptober' push to quit smoking is useful, but we need to look at why people start... especially when it's harder drugs

WARNING
Recreational drug use can be dangerous to your health and possession of certain controlled substances in the UK can result in an unlimited fine, prison sentence or both. For more information visit **talktofrank.com**

The modern world is awash with information about the dangers of so-called recreational drugs, yet drug-taking remains a problem. Why do so many people choose to put unfamiliar chemicals into their bodies, despite being told repeatedly that it's a bad idea? What compels us to take drugs at all?

There are many factors to consider when answering this question, the first of which can be categorised as biological.

Staunchly anti-drug types may insist that taking drugs is unnatural. Evidence suggests otherwise, however, because it seems that taking drugs is something our brains evolved to do.

Think about it: why would chemicals completely foreign to our biology interact with our brains at all, let alone so potently? And how would our bodies know how to break them down and flush them out? This suggests that our neurology and metabolism have been encountering drugs for long enough to evolve specific biological mechanisms for dealing with them.

It's believed that our pre-human ancestors regularly ate psychotropic or 'drug'-containing plants and gained survival advantages from them (such as more energy for hunting after consuming coca-like stimulants). Hence our brains and bodies evolved to take greater advantage of them. Accordingly, modern brains respond 'enthusiastically' to drugs.

Also, we experience pleasure from things we consume on a daily basis. The fact that foodstuffs trigger the reward pathway, which is the same part of the brain that's triggered by drugs, has been pointed out repeatedly in the media. Most people are familiar with the thought process that goes 'If I put this in my body, it will be enjoyable.' It stands to reason, therefore, that trying drugs isn't the huge conceptual leap that many might assume.

The second factor we have to consider is psychological. Sigmund Freud argued that humans are motivated to pursue things that provide pleasure and avoid things that induce pain or discomfort. With a mindset like that, who wouldn't try taking drugs?

ILLUSTRATION: BERNARD LEONARDO

"Psychology may also explain why the history of anti-drug campaigns is one of constant failure"

Luckily, it's not that simple. Humans are far more complex when it comes to motivations and decisions, and have ample exposure to the notion that drugs cause pain and distress. But even so, there are many psychological influences that increase someone's odds of trying drugs.

Our brains are constantly calculating whether the effort something requires is worth the potential reward. And if you're not persuaded about the dangers of drugs, they would appear to offer maximum reward for minimum effort. It's not all pleasure, though. The data shows many who take drugs have pre-existing mental health conditions, suggesting that self-medication is a strong driver.

Peer pressure and conformity are also important. Because the human brain is social, volumes of data about the dangers of drugs can still be less persuasive than friends saying, "It's fine, try it," because the latter is a more tangible, emotionally resonant source of information.

On top of this, group harmony also shapes our decisions. We often prioritise 'not rocking the boat' over our own wellbeing, so if the group we identify with is fine with taking drugs, we're likely to be okay with it too. Particularly when we're younger – adolescent brains are known to be far less risk-averse and more sensation-seeking, so experimenting with drugs is much more likely during your teens.

Psychology may also explain why the history of anti-drug campaigns is one of constant failure. Our innate desire for autonomy means that being told what to do by aloof authority figures will often make us want to do the opposite. If you tell people to 'Say no to drugs' without adequate justification, they're more likely to say no to that instruction.

Finally, the social category. Humans are products of the societies we grow up in. And, while many modern cultures adopt a dogmatic anti-drug stance, historically they've been far more drug friendly. Whether it's khat, hash, coca, psychedelics or communion wine, drugs have been a part of human societies for thousands of years. The 'just say no' approach is a tough sell when your culture has been saying 'yes' for millennia.

Perhaps anti-drug messages would be more convincing if they were more consistent. But they aren't. Impoverished people using heroin in a squalid bedsit is an image many anti-drug campaigns have used to discourage substance use. But wealthy people doing cocaine in a nightclub toilet? That's fine, apparently. You can run businesses, or even countries, if you do that.

Ultimately, biological, psychological and sociological factors all intersect to influence our attitudes to drugs. No one's denying drug abuse is a serious problem, but it's also a complex one. And we won't make any progress in tackling it if we ignore that last point.

DR DEAN BURNETT

Dean is a neuroscientist and author. His latest book, Emotional Ignorance, *is out now. (£14.99, Guardian Faber).*

COMMENT

WOMB TRANSPLANTS ARE NOW A REALITY AND THEY'RE CHANGING PEOPLE'S LIVES

There's new hope for the thousands of women who are unable to conceive or carry their own child

According to the World Health Organization, infertility affects one in six people worldwide. There are many causes of infertility in both men and women, and there are also many options to assist conception and pregnancy.

But for women with absolute uterine factor infertility (AUFI), things are more difficult. They either don't have uteruses (perhaps due to being born without a uterus because of a genetic condition or having had a hysterectomy at an age before starting a family), or don't have a functional uterus that's capable of carrying a pregnancy.

AUFI affects one in 500 women globally and approximately 15,000 women in the UK. Until recently, the only option for starting a family for these women has been through surrogacy and/or adoption.

Many women experiencing AUFI want to give birth to a child of their own, however. And science has now made that possible, thanks to uterine (womb) transplants, a procedure that has been developed over 25 years.

> "The recipient has had three periods – the first she has ever experienced"

So far, 90 women around the world have received uterine transplants, which have resulted in 49 babies. It is important to continuously monitor the development of these babies, especially as the sole goal of the uterine transplant is for a live birth of a healthy infant.

It's particularly relevant and promising to see that the babies have grown well during pregnancy, with no evidence of growth restriction, and are meeting age-appropriate neonatal and developmental milestones for the two years that they've been monitored.

The first uterine transplant in the UK took place earlier this year. The patient was a 34-year-old with a genetic condition called Mayer-Rokitansky-Küster-Hauser syndrome (MRKH), which affects one in 5,000 women. This means she has AUFI, as she was born with ovaries, but no fallopian tubes or uterus. She wants children, but specifically she wants to give birth and have a biological relationship with her offspring. This ruled out adoption and surrogacy.

But her sister, who doesn't have MRKH – and was born with ovaries, fallopian tubes and a uterus – wanted to donate her uterus to help enable this. She had completed her family, having had two successful, uncomplicated pregnancies and given birth to two healthy babies.

Both women had to undergo significant pre-op medical and psychological preparation to ensure their health and well-being were optimised and the operation could be a success. The operations for both women involved major surgery, which carries its own risk.

In addition, the major concern for a recipient is the possibility of their body rejecting the donor womb. To avoid this, anti-rejection drugs and close post-operative monitoring are used to boost the chances of a successful transplant.

The operation to retrieve the uterus from the donor took 8 hours 12 minutes, while the implantation took 9 hours 20 minutes. The most difficult stage of the procedure is preserving the blood supply, and transplanting and establishing a connected blood supply in the recipient as quickly as possible.

Provided rejection is avoided, testing the function of the uterus and the success of the transplant initially comes down to the recipient having a period, which provides evidence that the ovaries and uterus are working together throughout a menstrual cycle. At the time of writing, the recipient has had three periods – the first she has ever experienced. She is now planning to undergo embryo transfer later this year.

If the patient becomes pregnant and everything progresses normally, the baby will be delivered by C-section. She can then choose to try for a second baby in due course, should she wish. The uterus will then be removed and the immunosuppression treatment stopped, thus removing the associated risks.

Joint team leader and consultant transplant surgeon, Isabel Quiroga, said the patient was "incredibly happy" following the lengthy operation. "She was absolutely over the Moon, very happy, and is hoping that she can go on to have not one but two babies," she added.

"Her womb is functioning perfectly and we're monitoring her progress very closely. As a team, we're incredibly proud to contribute to this programme and we hope that it'll lead to many other women benefiting from this procedure."

The charity Womb Transplant UK is now working to fund a uterus donor programme for women who may wish to donate their uterus while they're alive or after their death. The charity hopes the surgery's success will mean "womb transplants become a sustainable option for women currently unable to bear their own children to realise their dream." SF

DR MICHELLE GRIFFIN

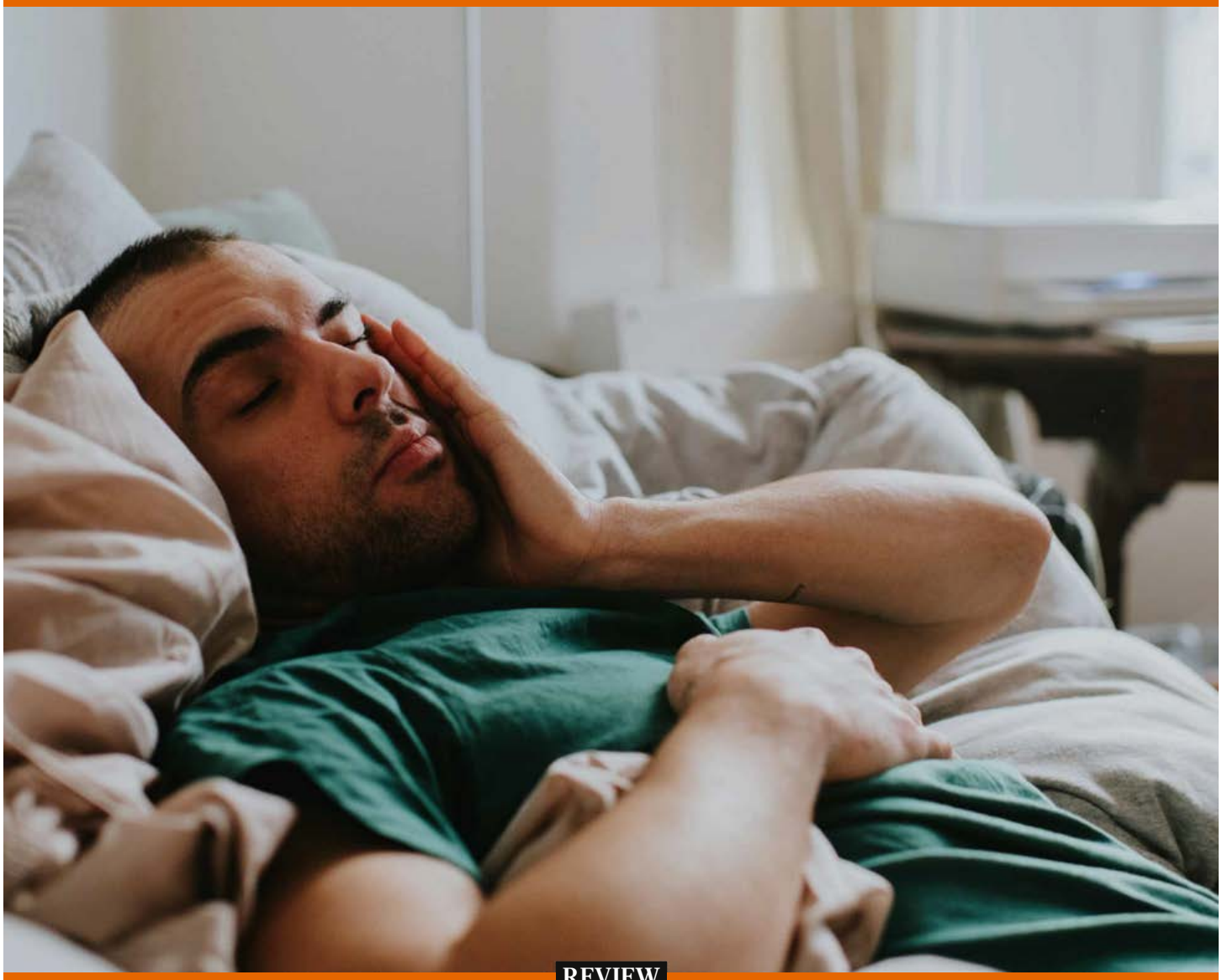
Michelle is the director of MFG Health Consulting, as well as a women's health expert and strategy advisor in women's health tech.

ILLUSTRATION: CHIARA XIE

REALITY CHECK

THE SCIENCE BEHIND THE HEADLINES

Sick days | Antigravity | Personality disorder



REVIEW

SICK DAYS: WE'RE TAKING MORE THAN EVER. SO WHAT'S KEEPING US AWAY FROM WORK?

Is the health of the UK's workforce at an all-time low, or has the nation's 'willingness to work' really changed? Maybe there's another explanation...

"The average employee took just under eight days of sick leave in the past year – two more than in pre-pandemic 2019 and more than in any year since 2008"

BBC *For more fact-checking news, visit the BBC's* Verify *website at* ***bit.ly/BBCVerify***

New figures suggest the number of sick leave days taken by UK workers is at its highest level in 15 years. Does this mean we're in poorer health and, if so, what's keeping us away from the workplace? A couple of years ago, COVID would have been the obvious culprit, but is it still to blame? And what can we do to keep people working? Well, the devil's in the data – if you know where to look…

ARE WE REALLY TAKING MORE SICK DAYS?

The worrying new numbers originate from the Chartered Institute of Personnel and Development (CIPD), an independent, non-profit, human resources organisation that has been reporting on sickness at work for more than 23 years.

Figures from its latest report were collected from the human resources departments of 918 organisations and cover a total of 6.5 million UK workers. They show that the average employee took just under eight days of sick leave in the past year – two more than in the pre-pandemic year 2019 and more than in any year since 2008.

The Office for National Statistics (ONS), however, puts the average number of sick days at closer to six, drawing from telephone surveys of 100,000 people. But the ONS data also shows a sharp rise in sick leave compared to pre-pandemic years.

Rachel Suff, senior policy adviser at the CIPD, says looking at both sets of data can provide a more nuanced picture, though she notes that the CIPD figures cover a "significant section" of the UK workforce.

Asked if the figures mean we're actually getting sicker, Dr Parth Patel, a senior research fellow at the Institute for Public Policy Research, told *BBC Science Focus*: "It's certainly a barometer for something not being quite right in our society."

Broadly, he adds, there are two explanations: either there really is more sickness or, for some reason, people are now more likely to take sick leave than they were before.

If anything, though, the CIPD figures seem to underestimate sickness rates, as levels of presenteeism (working while you're sick) are also up. Plus, the figures only consider people who are active in the workplace, when there is, in fact, a record number of people – over 2.5 million – who are now economically inactive due to long-term illness, according to the ONS.

WHAT'S KEEPING US AWAY FROM THE WORKPLACE?

ONS data for 2022 shows minor illnesses rose substantially that year, although they are only now returning to pre-pandemic levels.

So-called 'other' reasons for being off work – which include COVID, accidents, poisonings and respiratory conditions – are also much higher than in 2019.

The CIPD data, however, tells a slightly more complex story by breaking down the reasons for sick leave into short- and long-term illness, and asking companies to report the top three reasons in each category. Looked at in this light, the data reveals →

GETTY IMAGES X2

ABOVE The rise in the amount of sick days we're taking, especially relating to mental health, is concerning experts

→ the increasing impact of mental health issues in the workplace, with 63 per cent of organisations listing mental health in the top three reasons for illness lasting longer than a month, and 37 per cent listing stress as a reason.

"Mental health has been an increasing cause for concern for many years," says Suff. "But the last three years have been really challenging for people."

She cites the long tail of the pandemic and the cost of living crisis as factors affecting people's wellbeing, but points to data from the report suggesting that heavy workload is the reason most often given for stress-related absence.

Trying to tease out how COVID plays into all of this is by no means straightforward, partly due to low levels of testing at the moment. While the CIPD data includes a separate category for the virus, it could easily be mistaken for other minor illnesses such as colds or flu, which are listed by 94 per cent of organisations as a main cause of short-term sickness.

Any long-term impacts of COVID are even harder to decipher. But, according to Patel, it's unreasonable to think that the big spike in sick leave is all due to COVID. "I think that's obviously not true," he said.

SO, WHAT NEEDS TO CHANGE?

According to Suff, it's crucial that organisations get a better handle on what's causing sickness absences, not just in the general population, but among their own staff.

"The pandemic and mental health – they're all part of the bigger picture," she says. "But you've got to drill down into what's going on in your organisation, look at all the data and then see what you can do to support people better."

by **HAYLEY BENNETT**

Hayley is a science writer based in Bristol, UK.

ANALYSIS

ANTIGRAVITY: A RECENT TEST RESULT MIGHT HAVE RULED IT OUT

Hoverboards and flying cars may be off the cards... but dark energy may yet come to the rescue

According to first Newton, then Einstein, and now an experiment at CERN, gravity is an attractive force that exists between all objects in the Universe. That includes objects that have no mass, because gravity acts on energy, and mass is just one form of energy (as Einstein's most famous equation states, energy is equal to mass multiplied by the square of the speed of light). This is why even massless photons of light, travelling from distant stars, have their paths bent as they pass massive galaxies on the way.

Antigravity is a hypothetical repulsive gravitational force. In some ways, it sounds obvious that it should exist. There are both attractive and repulsive electric forces, so why not the same for gravity?

The difference is that electric charge comes in two types, positive and negative. Different charges (a positive and a negative) will attract each other, while charges that are alike (two positives or two negatives) repel each other. The equivalent of 'charge' for gravity is energy, and it only comes in one type: positive.

As these positive energies attract each other there doesn't seem to be room for antigravity, which is a pity because it would be a great way of flying around without the need for rockets, jet engines or even wings.

However, there is (or was, until this month) a possible get-out clause for antigravity: antimatter.

Antimatter isn't hypothetical, it's very real. Particles such as electrons have an antimatter equivalent. The antiparticle of the electron is the positron, and it has not only been observed, but is regularly used in hospitals for diagnostic purposes.

Positrons emitted from unstable elements injected into a patient's body will give off a very distinctive energy signal when they meet an electron and annihilate. The signal is so distinctive that the point of annihilation can be identified very precisely.

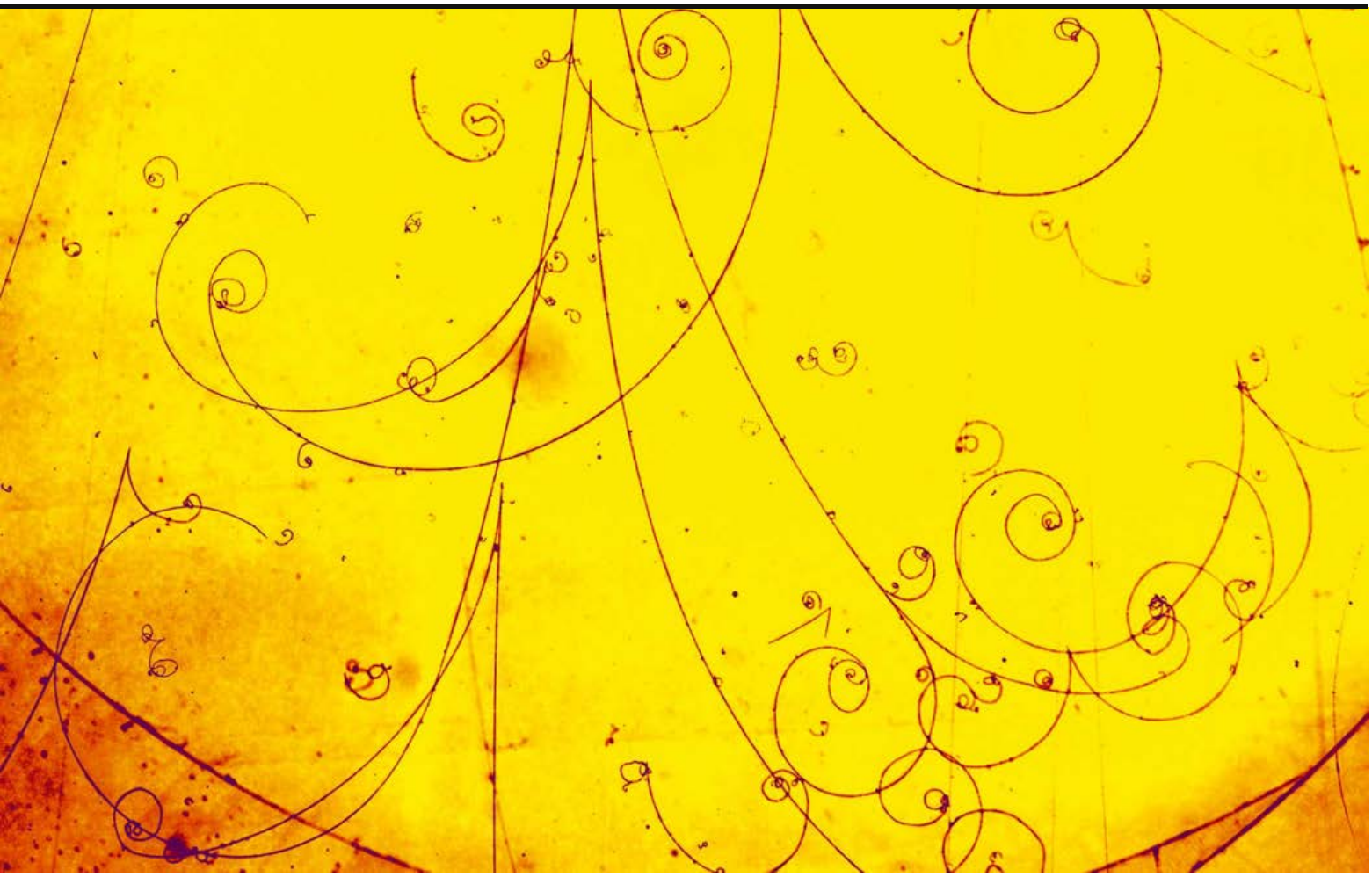
The whole process, known as Positron Emission Tomography (PET), gives doctors unique information on the soft tissues and flow of material around a body.

Antimatter has the opposite electric charge to matter, so does it also have the opposite gravitational charge, and so experience antigravity? This was the question the ALPHA-g experiment at CERN was designed to answer. Does antimatter fall down or up?

Producing antiparticles is quite easy. Accelerators such as those at CERN can make many positrons

GETTY IMAGES, SCIENCE PHOTO LIBRARY

"In some ways, it sounds obvious that it should exist. There are both attractive and repulsive electric forces, so why not the same for gravity?"



and antiprotons. That's fine, but these particles have electric charge, and they are also in general moving at high speed. Neither of those things is good if you want to measure the effect of gravity, because gravity is really, really weak.

Just think: your muscles, which use the electromagnetic force, can pick up a pen or paper, thereby counteracting the gravitational attraction of an entire planet.

So any tiny stray electric field in your experiment could easily obscure the effect of gravity on a charged particle like a positron or antiproton. And anyway, they'll have sped away before you could see which way they fall. The antiproton decelerator at CERN is designed to combat this; to slow down antiprotons, and eventually bring them together with positrons to make electrically neutral antihydrogen. In a similar way in which an atom of hydrogen is made up of a single proton and an electron, an atom of antihydrogen is made up of a single antiproton and a positron.

ABOVE Tracks of electrons and positrons. The antiparticle of the electron, spiralling anticlockwise, is the positron, spiralling clockwise

The ALPHA (Antihydrogen Laser Physics Apparatus) experiment at CERN's Antimatter Factory has seen researchers collecting antihydrogen atoms and studying them since 2013, and this month they published results from a new setup, called ALPHA-g, where the g stands for gravity.

The idea is very simple – trap a few hundred antihydrogen atoms in a vertical tube, let them →

ABOVE The Antimatter Factory at CERN where the ALPHA experiment studies symmetries between matter and antimatter

→ diffuse around, and measure how many come out of the top and how many come out of the bottom. The experiment is structured so that if gravity affects antimatter in the same way it affects matter, 80 per cent of them should drop out of the bottom, while 20 per cent would diffuse out of the top of the experiment by 'bouncing' up.

Within the precision of the experiment, that's exactly what happened. Antimatter falls down, like normal matter. Now, is this the end of the road for antigravity? Not really.

But it does signal the end for a certain type of antigravity. We won't be getting antigravity rockets (or hoverboards) riding on a cushion of antimatter, for example.

However, while most scientists are profoundly unsurprised by this result, a form of antigravity is actually built into our current best understanding of cosmology. Astrophysical measurements indicate that the rate of expansion of the Universe is increasing, meaning that some force is counteracting the gravitational attraction between the matter in the Universe, and actually pushing it apart. We call this dark energy, but we could just as well have called it 'antigravity'.

In fact, there were even cosmological theories that proposed that half the Universe was made up of antimatter, and that this was repelling the matter and thus providing the dark energy effect.

Such ideas also potentially solved some other problems with our understanding of cosmology – although they created a whole bunch more. Either way, in light of the ALPHA-g result, it seems they're wrong, and there must be something else behind the antigravity.

by **PROF JON BUTTERWORTH**
Jon is a Professor of Physics at University College London. He works on the ATLAS experiment at the CERN Large Hadron Collider.

COMMENT

BORDERLINE PERSONALITY DISORDER: WHY IS IT STIGMATISED?

Despite being recognised for decades, the condition remains misunderstood and undertreated as a result

The so-called 'personality disorders' are among the most controversial and complicated of psychiatric diagnoses. Critics say that stigma is baked into the concept itself – the label implies that there is something pathological about a person's personality.

The term 'personality disorder' is meant to reflect how a person's psychological problems are long-lasting and permeate many aspects of their lives, from their daily emotional experiences to their relationships.

For some, receiving a formal diagnosis of a personality disorder can help them understand why they find life so difficult and, in positive cases, it can help them obtain the professional support they need.

Of the 10 specific personality disorders recognised by psychiatry, among the most widely misunderstood is borderline personality disorder (BPD), which is estimated to affect one to two per cent of the population.

The term 'borderline' is a throwback to the 1930s. During this time, psychoanalytically trained psychiatrists saw the diagnosis as being on the margins of the now largely defunct categories of the psychoses (conditions that were considered more serious and untreatable) and the neuroses (conditions that were considered treatable with psychoanalysis).

People with BPD typically experience a lot of anxiety; they worry about being abandoned by people close to them; they often struggle to form a stable sense of who they are; and they can find stress particularly difficult to cope with.

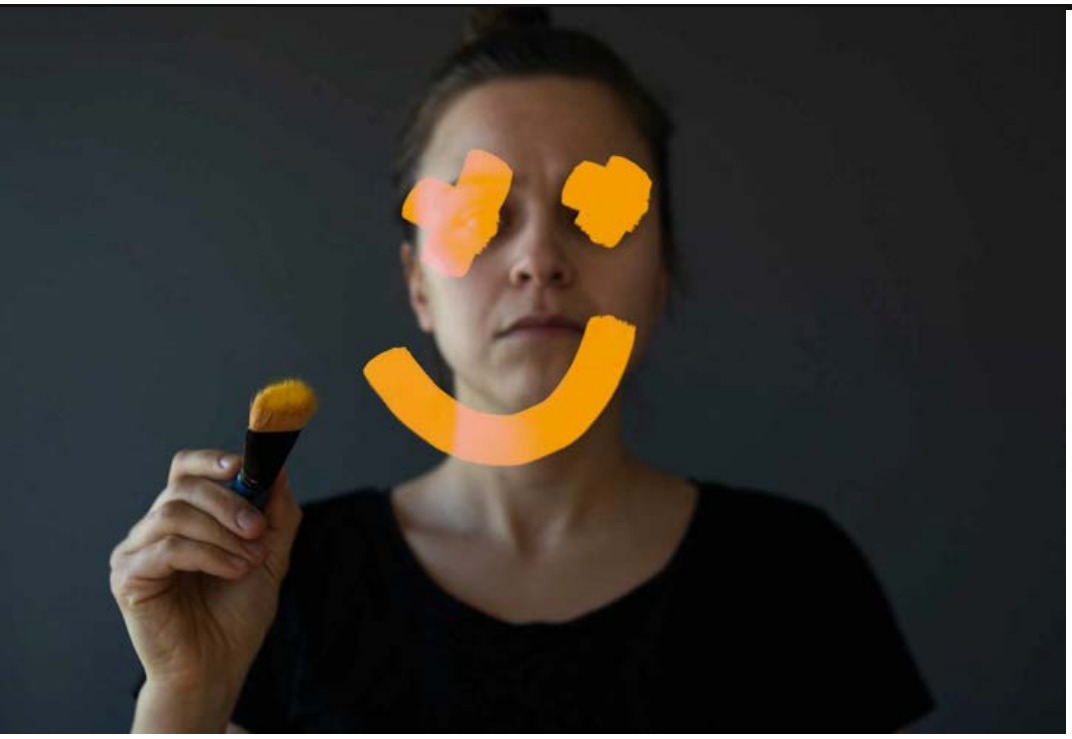
It can prompt them to act impulsively, to experience paranoid feelings or a sense of being detached from reality. To try to cope, people with BPD will often self-harm and they might think about taking, or try to take, their own life.

As well as fearing abandonment, another common experience for people with BPD is to swing from one extreme to the other in terms of how they feel about people close to them. One day they see family and friends as perfect, the next they believe those same people have let them down and are really bad. Inevitably, this can contribute to difficulties in close relationships for everyone involved.

There are competing theories for what is going on in BPD. For instance, one influential account states that BPD is an emotional regulation problem – people with the condition experience particularly intense and prolonged difficult

MAXIMILIEN BRICE/CERN, GETTY IMAGES

"Compassionate experts today recognise that what people with the diagnosis need, above all, is love and support"



emotions. Another theory holds that BPD is primarily rooted in difficulties interpreting other people's feelings and intentions, manifesting as a kind of hypersensitivity to perceived slights.

Sadly, there is evidence that BPD tends to be stigmatised in everyday conversations and media portrayals, which can pander to 'crazy person' stereotypes and emphasise the person's troublesome behaviour, rather than what it's like for them to live with their psychological difficulties. Perhaps worse, many clinicians also tend to hold negative and pejorative views towards people with diagnosed BPD.

For example, surveys show mental health professionals saying they'd rather avoid this patient group and feel less optimistic about helping them. Harmful misguided beliefs that swirl around and feed these prejudices include the notion that people with this condition are untreatable or are deliberately manipulative.

Trusted and compassionate experts today recognise that what people with the diagnosis need, above all, is love and support. We should see behaviour associated with BPD, including self harm and excessive worry about being abandoned, not as forms of attention seeking or manipulation, but rather as consequences of the intense emotional discomfort that people with BPD experience.

Many people with BPD have difficult pasts – suffering childhood maltreatment is the most significant risk factor for being diagnosed with the condition. Contrary to the widespread misconception that BPD is untreatable, in fact there are now well-developed methods for helping people with the diagnosis.

Probably the most well-supported is known as Dialectical Behaviour Therapy, which is a specialised form of Cognitive Behavioural Therapy. Its emphasis is on helping people with BPD better manage their emotions, to better understand other people's behaviour and emotions, to increase their confidence and self-esteem and to develop skills around socialising and self-awareness.

Whatever treatment approach is used, experts emphasise that it's important for the therapist not to be judgmental and to adopt a warm, supportive, collaborative style of working.

There are drug treatments available too, but these are generally seen as an adjunct to psychotherapy – to help the person with BPD cope with some of their more troubling symptoms while working on their emotional and other skills in therapy.

Promisingly, there's some evidence that simply learning trustworthy background information about BPD can help people with the diagnosis feel more hopeful and better understand their experiences. What's more, it's being proven that educating clinicians about BPD can improve their attitudes to it too. SF

by DR CHRISTIAN JARRETT

Christian is a cognitive neuroscientist and the author of books on psychology, neuroscience, and self-help. His latest book is Be Who You Want: Unlocking the Science of Personality Change *(£14.99, Robinson).*

Christmas cheer delivered all year!

Gift subscriptions FROM JUST £26.99!

Give a gift they'll really appreciate month after month with a subscription to one of our magazines

CRAFT

13 ISSUES FOR £46.99
SAVE 50%

13 ISSUES FOR £59.49
SAVE 50%

13 ISSUES FOR £59.49
SAVE 50%

13 ISSUES FOR £69.49
SAVE 52%

LIFESTYLE

13 ISSUES FOR £44.99
SAVE 50%

13 ISSUES FOR £34.99
SAVE 49%

13 ISSUES FOR £34.99
SAVE 51%

CRAFT

13 ISSUES FOR £51.49
SAVE 50%

13 ISSUES FOR £46.29
SAVE 50%

13 ISSUES FOR £46.29
SAVE 50%

13 ISSUES FOR £42.99
SAVE 50%

SPORT

13 ISSUES FOR £39.99
SAVE 54%

13 ISSUES FOR £39.99
SAVE 52%

13 ISSUES FOR £34.99
SAVE 51%

HOMES & GARDENS

13 ISSUES FOR £34.99
SAVE 51%

13 ISSUES FOR £34.99
SAVE 51%

13 ISSUES FOR £26.99
SAVE 41%

13 ISSUES FOR £26.99
SAVE 41%

SCIENCE & NATURE

14 ISSUES FOR £39.99
SAVE 52%

12 ISSUES FOR £35.99
SAVE 50%

13 ISSUES FOR £34.99
SAVE 51%

GREAT REASONS TO SUBSCRIBE

Gift subscriptions from just £26.99! • Free delivery direct to your door • Fantastic Christmas savings

YOUR TWO EASY WAYS TO ORDER

Visit **ourmediashop.com/xmas23**

Call **03300538660 quote code X23OMHA**

SCAN ME

This offer closes on the 31st December 2023 and is valid for UK delivery addresses only. The discounts shown are savings calculated as a percentage of the full shop price. For overseas rates visit www.ourmediashop.com. All Christmas gift subscriptions will start with the first issue available in January 2024. Should the magazine change in frequency, we will honour the number of issues and not the term of the subscription. †UK calls will cost the same as other standard fixed line numbers (starting 01 or 02) and are included as part of any inclusive or free minutes allowances (if offered by your phone tariff). Outside of free call packages call charges from mobile phones will cost between 3p and 55p per minute. Lines are open Mon to Fri 9am – 5pm.

INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

REVIEW
SONY WF-1000XM5
These new wireless, noise-cancelling earbuds are put to the test **p38**

BREAKTHROUGH
AUDIO APPAREL
Haptic vests are enabling people with hearing difficulties to enjoy music **p40**

NEW TECH
IDEAS WE LIKE
Our pick of this month's greatest new gadgets **p42**

Car brand Mini collaborates on a limited-edition e-bike **p43**

1989
The year the first noise-cancelling headphones were released

$22 BILLION
The approximate value of the global headphone market

30 PER CENT
Sony's share of the headphone market around the world

REVIEW

Sony WF-1000XM5: An audio home run, but in a smaller package

Alex Hughes tries out Sony's tiniest earbuds to date to see if it's possible to pack a bigger musical punch into a smaller package

The earbud market is crowded… really crowded. There are more options than ever, and while some brands are happy to charge into the hundreds or, in some cases, thousands, you can just as easily score earphones for a few quid. Sure, the performance isn't great at that price, but at what point does your money stop securing better quality?

You can ask this question about Sony's new WF-1000XM5 wireless earbuds, which will set you back £259. As the latest in the brand's legendary in-ear series, there's a lot of hype to live up to. Can they improve on what was already an almost flawless pair of earbuds? Or is this simply a pricey cosmetic upgrade more than anything else? I spent time with the WF-1000XM5 to find out.

Without the right knack, removing Sony's new WF-1000XM5 earbuds from their smaller case can be a tricky proposition

DESIGN

Sound quality is obviously the priority, but the charging case is also a crucial part of any earbud package. Sony has spent a lot of time focusing on the charging case for the WF-1000XM5 and has trimmed down its size drastically. This version takes up very little space and fits comfortably in the palm of your hand.

Made with a premium plastic, the case feels well-built all over. The smaller size does make it a challenge to open one-handed, however. It's possible, but requires some finger gymnastics to release the clasp and close it again.

The challenges continue once the case is opened, as removing the earbuds is also a fiddly job. The earbuds have been designed to be smaller than previous generations and while that's great in many ways, it does make it tricky to get your fingers around them in the case. There's a simple solution, however. Instead of trying to pluck them out, just click each earbud to the side. This action pulls them off the magnets and into your hand. Just make sure you catch them before they fall!

"THERE'S MORE FOCUS ON CLARITY, TO OFFER A LESS-ENHANCED, TRUER RENDITION OF THE MUSIC"

Being so small, the earbuds fit comfortably in the ear without feeling heavy. Even when jogging, there was little to no movement, a problem I've experienced with most other in-ear headphones.

FEATURES

Size isn't the only change on these earbuds, although it is the most obvious. The other new features are more subtle.

In terms of battery life, it comes in at around eight hours if both Bluetooth and active noise cancelling are activated. With the wireless charging case topped up to full, that adds on a further 16 hours.

While that doesn't sound like a lot, by the standards of high-end wireless earbuds,

Sony's newest earbuds fit securely in the ear and are unlikely to fall out while you're dancing or jogging

this puts the WF-1000XM5 at the top end of the scale for battery life.

Like many modern Bluetooth earbuds, the WF-1000XM5 have an external noise cancellation feature that can be switched off, if you choose. This means that you can either block out the sounds around you, or let them in if you want to be aware of them. Equally, there is an option for you to adapt the sound to your environment, so you can match the amount of ambient sound to the particular surroundings you find yourself in.

There may not be any buttons on the earbuds, but WF-1000XM5 have 10 actionable presses, ranging from skipping songs to volume adjustments and voice assistant activation. While it's useful to have these options, you'll need practice and a great memory to remember all of the different combinations on each side.

SOUND

It'll come as no surprise that the Sony WF-1000XM5 sound great. Following in the footsteps of their uber-popular predecessors, they have made some key improvements without compromising.

In fact, Sony has taken a slightly different approach with its latest earbuds. Previous Sony offerings tended to focus on delivering bass and a richer feeling. Now, there's more focus on clarity, to offer a less-enhanced, truer rendition of the music.

Take 'Go With The Flow' by Queens of The Stone Age. A song that, in the band's classic fashion, is aggressive on fuzzy guitar. Sony backs down on the bass,

Active noise-cancelling means you can keep the sounds of the outside world at bay

offering a clear rendition that allows the overall power of the guitar and drum combo to shine.

The same goes for songs that have a tendency to get muddled in the mix, such as 'I've Seen Footage' by Death Grips. At its best, this song rides the line between clarity and a hazy mess, but with these buds you're on the side of clarity.

When listening to Tool's 'The Pot', a six-minute exercise in metal restraint, the Sony WF-1000XM5 perfectly emphasises the powerful guitar and drums, while keeping the many parts of the complicated track noticeable.

This isn't to say the overall attitude of the songs is lost in favour of clarity. Stormzy's 'This Is What I Mean' experiences the full force of a bass-powered track without being tempered, enjoying the odd vocal ranges that Jacob Collier injects throughout.

VERDICT

The Sony WF-1000XM5 is another pair of great earbuds from the tech giant. Are they the best around for this price? It's debatable. Companies such as Bose and Jabra are closing in, but, for now, Sony remains a clear contender for the maker of the best earbuds.

The only complaints I can offer are small. A finicky case and touch controls that can be a pain to remember, are small problems to have with earbuds that feel, look and sound this good.

Of course, these aren't by any means cheap earbuds, and that's going to be the biggest factor to hold anyone back from investing in them. Are they worth the price? Of course, if you're a regular earbud wearer looking to block out the world. But if you're just looking for something to occasionally listen to music on the move with, it's a steep price to pay.

RATING

★★★★★

PROS

- Fantastic audio
- Comfortable and lightweight
- Good noise cancellation
- Solid battery life

CONS

- Fiddly case
- Strong competition at this price point

These vibrating vests bring music to life for deaf gig-goers

Haptic tech is making music accessible to people with impaired hearing

There's a long history of deaf people going to concerts and attending gigs using items such as inflated balloons or pipes to feel the vibrations of the live performance.

In spite of this, there remains a belief that anyone who is deaf is unable to enjoy live music. But while a deaf person may not be able to hear the sound of the music, they can feel it through the vibrations produced by the powerful speakers being used, or even the instruments themselves if they're close enough.

The US tech company Not Impossible Labs has seized on this concept and, in collaboration with musicians, venues, and production companies, built on it to create a haptic vest that makes these vibrations more accessible to both deaf and hearing music lovers.

GETTING SUITED UP

"Nothing is impossible forever," boasts the home page of notimpossible.com proudly in large font. A bold claim, but one that matches the unique nature of the products the company is working on.

Led by founder Mick Ebeling, Not Impossible Labs is built around innovation that provides accessibility where it wasn't previously available. While there's a lot of development occurring in the world of accessibility tech right now, Not Impossible Labs takes an unconventional route.

Whether it's helping blind skateboarders ride via echolocation; creating navigational 'super-hero' suits for a deaf and partially blind children, or something as simple as text messaging service that helps local people going hungry find food, Not Impossible has learned to think outside the box.

Its latest concept is called Music: Not Impossible, and the idea is to make music accessible to all, even those who can't hear it. Musician and inventor Daniel Belquer has designed haptic vests, wrist and ankle bands, which feature 24 touch points that can be synced to instruments and made to vibrate in time with the music they're playing.

The vests use a vibrating textile to translate the sounds into physical sensations. This, in theory, is a

"HAVING THE STRAPS AND THE VEST ON WAS LIKE BEING SLAPPED IN THE FACE... IT WAS FANTASTIC"

more nuanced alternative to techniques adopted by deaf concertgoers, such as standing close to the speakers, or holding a balloon to feel the vibrations.

The vests are now quite advanced, built with sturdy fabrics and vibrating packs across the body, but they didn't begin that way. Originally, the technology was tested by strapping vibrating smartphone motors to the body. This, however, lacked nuance and it required vast changes to get the vest to where it is now.

A NEW WAY TO EXPERIENCE MUSIC

The vests have been tested at gigs by musicians and spectators, and used by both deaf and hearing music fans. Australian production company The Newmarket Collective collaborated with Not Impossible to host an event called Across Silence in Melbourne in June to celebrate haptics and performance. Delivered in Auslan – the Australian form of sign language – the show was a celebration of accessibility, mixing sign language, performances and the haptic vests.

The performers included Walter Kadiki, a deaf poet who wore one of the vests throughout his performance. "I wanted to do a concert with deaf artists," Kylie Davies, director of The Newmarket Collective, told *BBC Science Focus*. "We came up with a concept and invited Walter and an actor to sign his poems to music.

"We had a pianist write music for Walter's poems and write music that was compatible with the vests – not too many notes at once to keep the different vibrations clear."

The Newmarket Collective's aim with the performance was to give the performers a deeper connection to the sounds that they were creating on stage, but the use of the vests wasn't the first option. "We looked into using wooden boards or how the floor could vibrate, and in my research I came across Not Impossible. Lots of meetings later, we flew Daniel Belquer over to help us."

A MULTITUDE OF SENSATIONS

This isn't the first time Walter Kadiki has looked towards vibrations to aid him with his compositions, as he's familiar with this kind of technology. "I have a SubPac [a haptic vest for enhancing bass]. It has one vibration that goes straight to the back. It was pretty good, but limited with that single vibration pattern," he says. "The vest we used for this performance has so many different areas where you feel the vibrations. In the wrists, the elbows, the shoulders, the chest, everywhere. You can really feel the individual instruments playing."

Because of this, Kadiki is able to isolate the vibrations of the piano and other individual sounds. With haptic devices that deliver just one vibration, the wearer can't pick up on the particulars.

"Having the straps and the vest on was like being slapped in the face. All of a sudden, you're getting a multitude of instruments and sensations. It was fantastic," says Kadiki. "[Especially for] the piano… I never knew there were different tunes. When we started and the piano began to play, there were all of these different notes. It was really unique for me."

For anyone who has heard music and experienced it in conjunction with its vibrations, it can be hard to explain the feeling. "It might be hard for a hearing person to understand," says Kadiki. "By removing our hearing, we can experience things very deeply. We know when music is beautiful and soft, or harsh. It's not something you learn in a day, but a lifetime of experiencing through vibration."

Ideas we like...

Our pick of this month's smartest tech

...A good pair of smart glasses

Ah smart glasses… the tech trend that refuses to die, no matter how many times it's killed. But now, as Amazon steps up to take another swing at it, we're actually feeling a little hopeful. The third generation Amazon Echo Frames avoid the usual mistake of trying to do too much, and instead keeps things simple. These glasses are minimalist and aesthetically pleasing, while also offering music streaming, voice assistant control, smart home interaction and a host of hands-free experiences. This could be the step in the right direction for smart glasses… or another failure to add to the pile.

Amazon Echo Frames
From $269.99, Amazon.com

↑ ...A Mini-malist e-bike

E-bikes aim to do away with the worst part of cycling: struggling up hills drenched in sweat. There are plenty of e-bikes out there already, but Angell's new collaboration with legendary car brand Mini could be one of the best. Each bike has a stylish dual-colour frame (either 'ocean wave green' or 'vibrant silver') and is part of limited edition – only 1,959 are available (to commemorate the year of the Mini's launch). Everything is built-in, including the motor, a GPS system, lights and mudguards. You just have to provide the power for the battery.

MINI E-Bike 1
€3,490, angellmobility.com

↑ ...A robotics kit for your kids

Do you like the idea of LEGO, but are looking for something with less emphasis on creative construction and more on computer coding? If so, ClicBot could be for you. Offering a collection of robot kits, ClicBot offers modular experimentation for any child showing an interest in robotics. The different parts can be switched around to create different robots that can be programmed through a basic child-friendly, drag-and-drop system. There are no tie-in Harry Potter, Marvel or Star Wars kits currently in the range though.

ClicBot Kits
From £416, keyirobot.com

↓ ...A new type of foldable device

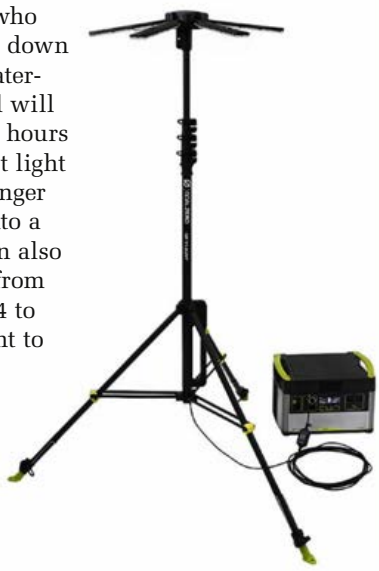
As tech companies run out of ways to improve their products, a new wave of weird and wonderful (possibly unnecessary) changes is emerging. Do you need a 3-in-1 laptop, desktop, tablet PC with a flexible screen? Probably not. But is it a really cool item with head-turning novelty? Yes! HP's Spectre Foldable PC has a 17-inch folding display and a keyboard to enable you to use it in whatever configuration best suits your circumstances. It's packed with high-end specs and has an eye-watering £5k price tag, but just think how cool you'll look doing computer origami in the coffee shop.

HP Spectre Foldable
£4,999.99, hp.com

↓ ...A superpowered solar light

There's nothing worse than trying to put a tent up by torchlight. Next time you arrive at your campsite after dark, light up the night with Goal Zero's Skylight. It's a fully portable floodlight that provides 6,000 lumens of illumination – enough to brighten up the landscape up to 300 feet away (good luck to your campsite neighbours who have bedded down early). It's water-resistant and will run for eight hours on the lowest light setting, or longer if plugged into a battery. It can also be adjusted from 1.2 to 3.6m (4 to 12ft) in height to *really* annoy people.

Goal Zero Skylight
$299.95, goalzero.com



IDEAS WE DON'T LIKE...

...A DESIGNER DUMB PHONE

Dumb phones are all the rage right now, offering a smartphone without the apps, games and distractions, and taking the device back to basics by only offering calls, texts and a hotspot. But, ironically, designer dumb phones are a dumb idea. Take the new Punkt MP02, for example – it costs £279, but looks like it was released among the first handheld devices. Featuring a tiny screen and a selection of buttons (how old school), the MP02 can text and call... and that's it. Want a distraction-free experience? Buy one of Nokia's equally stylish alternatives for a fraction of the price.

Punkt MP02 4G voicephone
From £279, punkt.ch

...A TELEVISION THAT'S JUST TOO BIG

Like smartphones, TVs started big and bulky, then got smaller, but are now heading towards gargantuan dimensions in order to bash all of your senses into oblivion. Samsung has been at the forefront of this 'drive for size' and is now releasing a ridiculously large 98in (250cm) 8K TV. We're not entirely sure where you would put it, or even why you would need it, but Samsung is determined to make sure it offers the full experience, so has packed it with AI visual enhancers, Dolby Atmos, anti-glare technology and more. But at just under $40K, we'd expect less of a 'full' experience and more of a life-changing one.

Samsung 98-inch TV
$39,999, samsung.com

SFP398

BBC Science Focus
SUBSCRIPTION ORDER FORM

Please complete the order form and send to:
FREEPOST OUR MEDIA (please write in capitals)

UK DIRECT DEBIT

☐ Yes, I would like to subscribe to/renew *BBC Science Focus* paying £39.99 every 14 issues – saving 52%*

YOUR DETAILS (ESSENTIAL)**

Title _____ Forename _____
Surname _____
Address _____
_____
_____ Postcode _____
Home phone no _____
Mobile phone no** _____
Email** _____

☐ **I wish to purchase a gift subscription**

GIFT RECIPIENT'S DETAILS (ESSENTIAL)**

Title _____ Forename _____ Surname _____
Address _____
Postcode _____ Home phone no _____
Mobile phone no** _____
Email** _____

Instructions to your bank or building society to pay by Direct Debit DIRECT Debit

To: the Manager (bank/building society)

Address

Postcode

Name(s) of account holder(s)

Bank/building society account number

Branch sort code

Reference number (internal use only)

Originator's identification number

4 4 3 7 7 3

Please pay APS RE Our Media Ltd debits from the account detailed in this instruction subject to the safeguards assured by the Direct Debit Guarantee. I understand that this instruction may remain with APS RE Our Media Ltd and, if so, details will be passed electronically to my bank/ building society.

Signature

Date / /

Banks and building societies may not accept Direct Debit mandates from some types of account

KEEP IN TOUCH

****BBC Science Focus* would love to email you with updates, special offers and promotions. You can unsubscribe at any time. Please tick here if you would like to receive these ☐**

We'd also love to tell you about other offers and promotions from our publisher, Our Media Limited. If you'd rather not be contacted this way please tick here: ☐ Post ☐ Phone. Your data will be held by Immediate Media Company Limited (a parent company of Our Media Limited). For information about how we protect your personal data, please see our privacy policy, which can be viewed online at www.immediate.co.uk/privacy-policy

OTHER PAYMENT METHODS

☐ **UK cheque/credit/debit card** – £62.89 for 14 issues, **saving 25%**
☐ **Europe** inc Eire – €114.00 for 14 issues
☐ **Rest of world** – $137.00 for 14 issues
☐ I enclose a cheque made payable to Our Media Ltd for £ _____

Visa ☐ Mastercard ☐ Maestro ☐

☐☐☐☐ ☐☐☐☐ ☐☐☐☐ ☐☐☐☐

Issue no ☐☐ Valid from ☐☐☐☐ Expiry date ☐☐☐☐

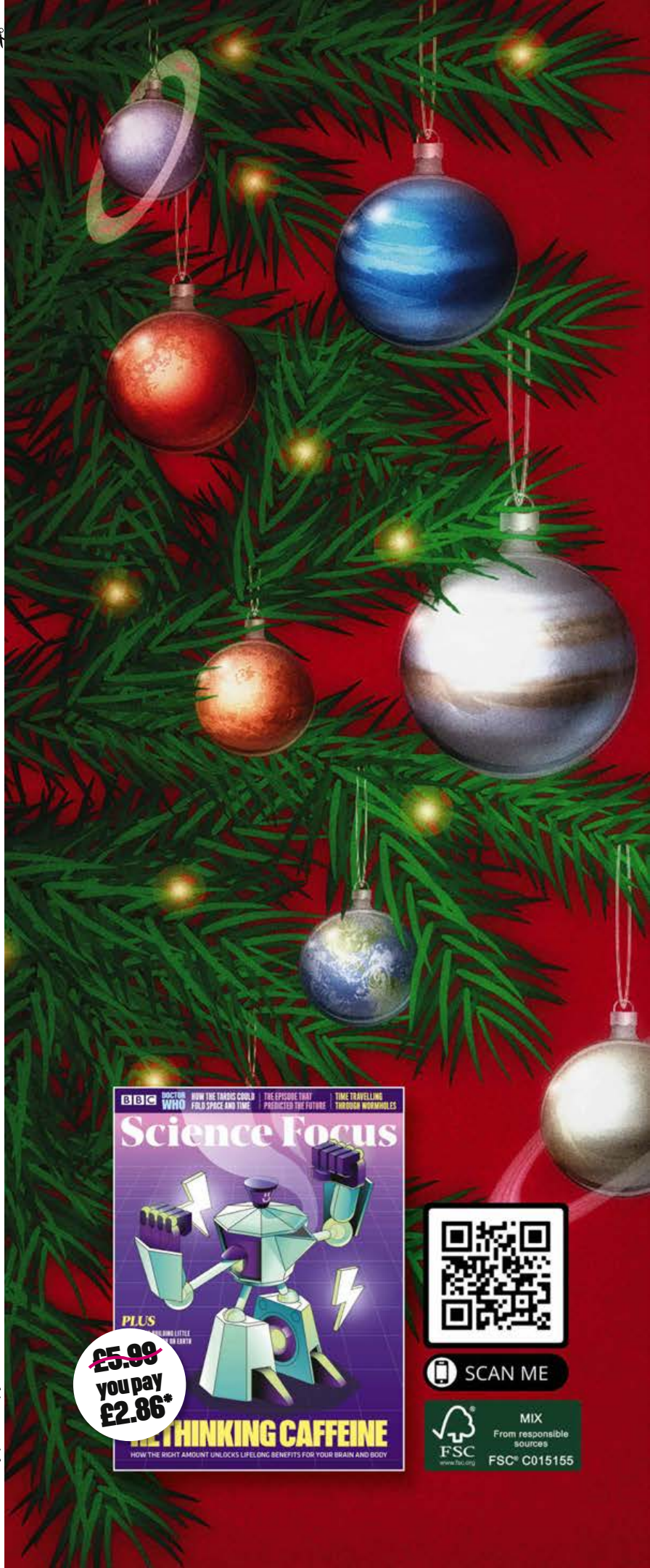
Signature _____

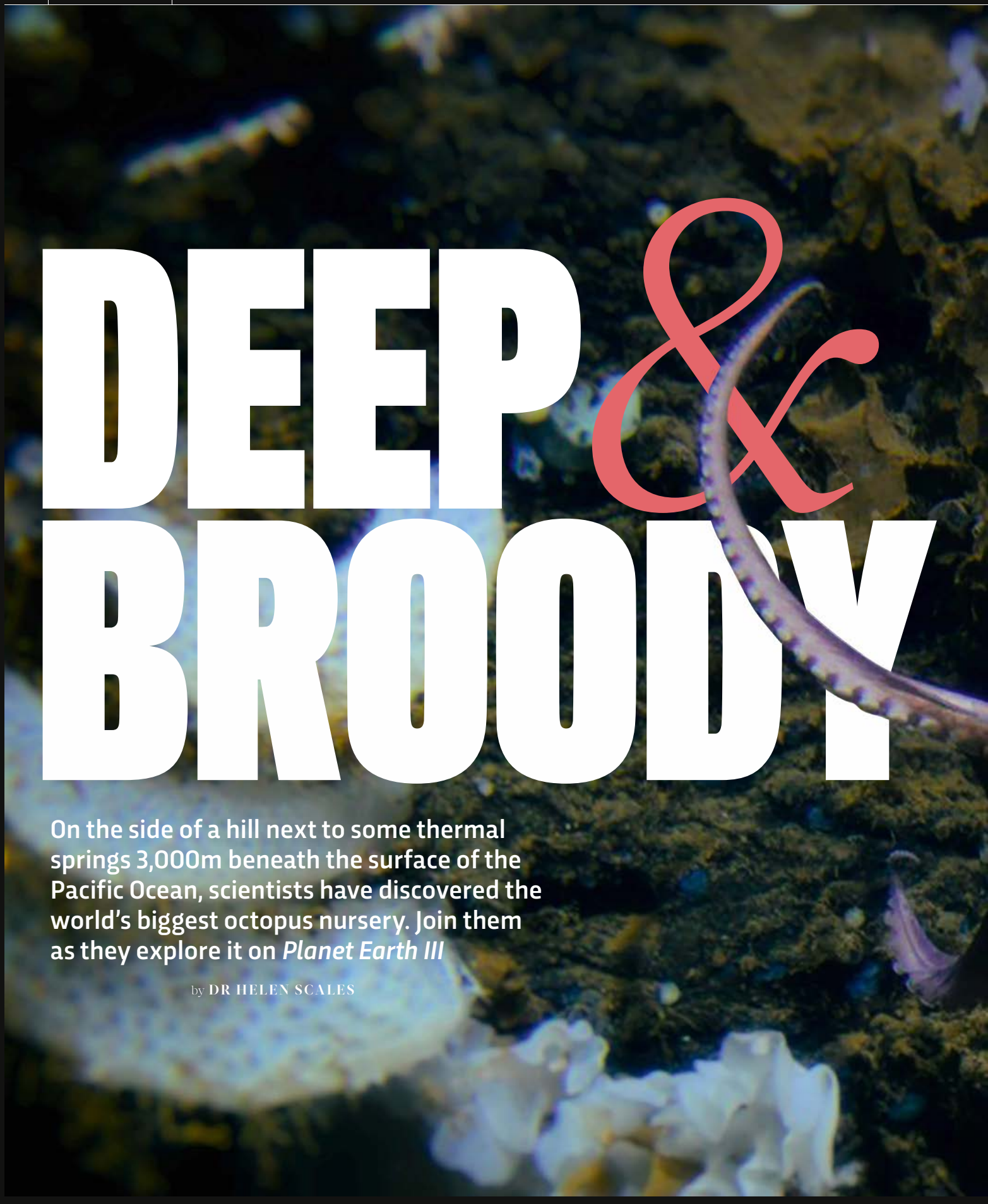
Date _____

If credit card address is different, please use the order hotline 03330 162113
OVERSEAS Please complete the order form and send to: *BBC Science Focus Magazine*, PO Box 3320, 3 Queensbridge, Northampton, NN4 7BF

***Offer ends 31 December 2023.** 52% saving is only available to UK residents. Personal subscriptions will start with the next available issue. Gift subscriptions will start with the New Year issue mailed out after Christmas.

You may photocopy this form





DEEP & BROODY

On the side of a hill next to some thermal springs 3,000m beneath the surface of the Pacific Ocean, scientists have discovered the world's biggest octopus nursery. Join them as they explore it on *Planet Earth III*

by DR HELEN SCALES

PHIL TORRES/GEOFF WHEAT/NSF

BBC ONE

Find out more about the Octopus Garden by watching **Planet Earth III**

A mauve arm, covered in suckers, gently unfurls and tends to a clutch of eggs shaped like elongated ping pong balls. Puffs of water from the siphon on the side of the octopus's head ensure her unhatched young get plenty of oxygen. She's surrounded by hundreds of other females which, when viewed from a distance, live up to their nickname. Pearl octopuses (*Muusoctopus robustus*) resemble spherical gems sitting on the seabed.

This is the largest known aggregation of eight-armed molluscs on the planet – around 20,000 – and it's being witnessed by people all around the world in stunning high definition in the 'Oceans' episode of the BBC series *Planet Earth III*.

This view would have been astonishing enough had it come from somewhere in the shallow seas, a tropical coral reef or a kelp forest, but these octopus mothers are tending their eggs almost 3km (2 miles) below the surface, in the freezing cold and darkness of the deep sea.

"The fact life is there at all is amazing," says producer and director Will Ridgeon, who spent two years filming the octopuses and collaborating with scientists and engineers at the Monterey Bay Aquarium Research Institute (MBARI) in California.

The Octopus Garden, as the site is now known, is located in the eastern Pacific, 160km (100 miles) southwest of Monterey Bay, on a hillock near a giant underwater mountain called Davidson Seamount.

The site was discovered in 2018 during an expedition that was being livestreamed over the internet. It was the first time anyone had seen so many of these creatures in one place, let alone in the deep sea (octopuses are notoriously solitary animals and when kept together in captivity they tend to become cannibalistic).

Ridgeon was watching the livestream of the discovery and immediately knew this was a story to film for the new BBC series. He teamed up with Dr Jim Barry, senior scientist at MBARI, who started making regular visits to the Octopus Garden in 2019 to learn more about why so many octopuses congregate in that particular spot. "The question was, why there?" says Barry.

Barry and his colleagues brought together specialised tools to launch a series of detailed studies. They created a photomosaic of a 2.5-hectare (almost 27,000ft^2) portion of the site, stitching together high-resolution images that let them count individual octopuses. They also set up time-lapse cameras on the seabed, which snapped close-up pictures every 20 minutes for months at a time, to show what the octopuses were up to. And gradually, Barry's team began solving some of the Octopus Garden's biggest mysteries.

ABOVE The aptly named pearl octopuses tend their eggs in the Octopus Garden, among the flower-like sea anemones

"THE DESCENT TO THE OCTOPUS GARDEN CAN TAKE UP TO TWO HOURS"

WORKING REMOTELY

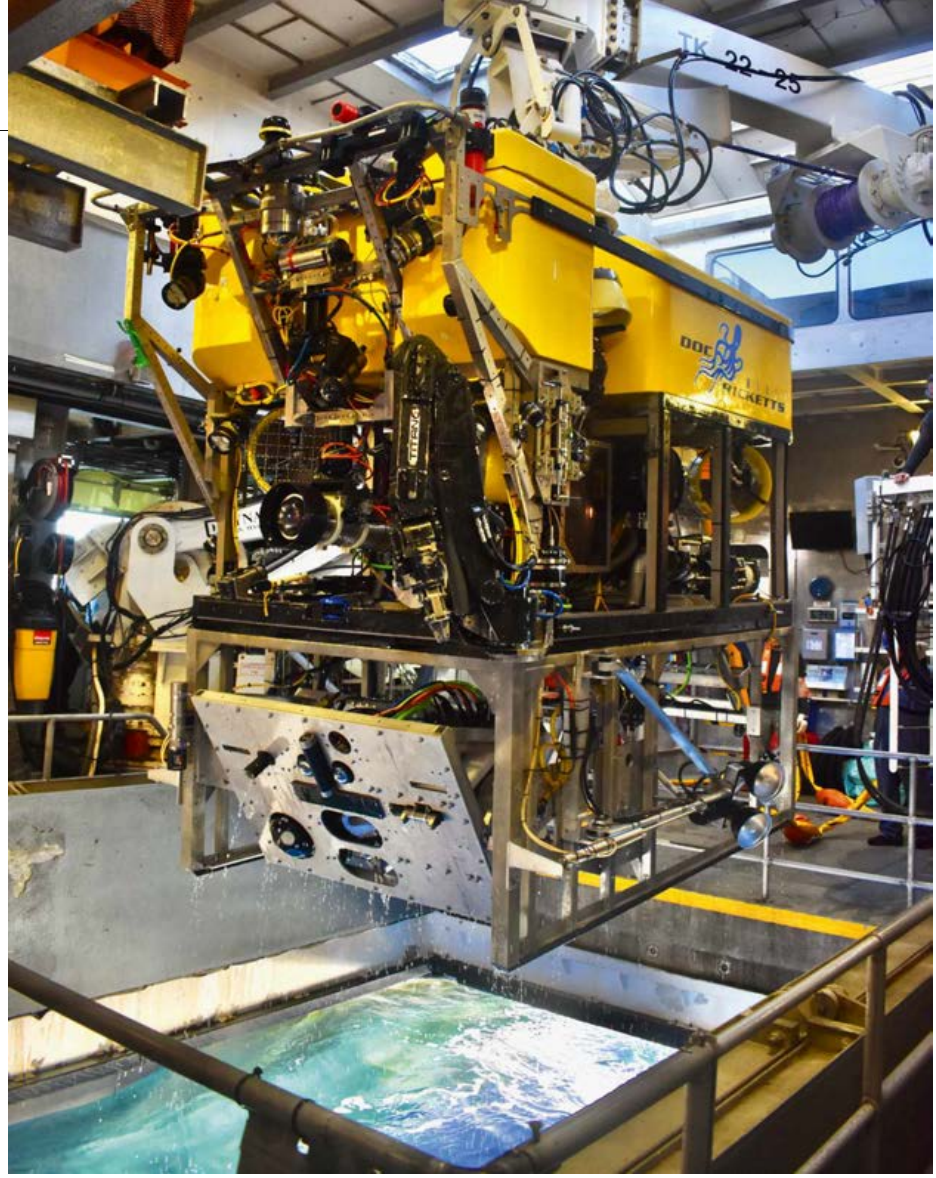
Ridgeon got involved in the expeditions to the Octopus Garden early on. At first the shoots took place during lockdown, so he joined via live video link from his bedroom in Bristol, UK (occasionally interrupted by his five-year-old daughter).

When COVID-19 restrictions allowed, Ridgeon joined Barry and his team on MBARI's ship, the research vessel *Western Flyer*. But none of them visited the Octopus Garden in person. All the research and filming was done using a car-sized remote-operated vehicle, or ROV, equipped with cameras and robotic arms.

The dives started around 6am, when the ROV was lowered into the sea through a hole in the *Western Flyer*'s hull called a moon pool. "It's quite James Bond," says Ridgeon.

The descent to the Octopus Garden can take up to two hours and the ROV stays down there for the entire day. Pilots control the ROV via a cable linking it to a control room on the ship at the surface, where everyone watches the video feed to see what's going on below.

MONTEREY BAY AQUARIUM RESEARCH INSTITUTE X3



ABOVE The remote-operated vehicle used to study and film the octopuses is launched through a hole in the research vessel's hull

"You forget you're looking at screens," says Ridgeon. "You think you're down there."

Engineers at MBARI worked with the BBC to find the ideal camera set-up to film the Octopus Garden. It wasn't possible to use footage from cameras fixed to the ROV, because there's too much vibration. "The BBC can take care of a little bit of that [shivering]," says Barry, "but not as much as we had."

The ROV 'shivers' not because of the cold temperatures in the deep, but because its thrusters have to run constantly to ensure it stays down near the seabed (the ROV is positively buoyant, so it will float back to the surface if it malfunctions). To get around that, Barry and Ridgeon used a separate 4K camera on a specially designed stand that they could place on the seabed. "That was the secret, I think, behind the images," says Ridgeon.

Unlike the cameras on the ROV that the scientists use, which can only get within a couple of metres of a subject on the seabed, the 4K camera has a focal length of around 20cm (7-8in) and could get right among the octopuses. But it was difficult to use. It took up to 40 minutes to position, then the team had to hope it wouldn't fall over and that the action would take place in front of it.

Ridgeon operated the camera from the ship, using a PlayStation controller MBARI engineers had adapted for the task. "It's like trying to film with your hands tied behind your back, at first," says Ridgeon.

Another challenge of filming in the deep sea is light. "You want to get your lights as far away from the camera as possible, →

ABOVE To get the footage for *Planet Earth III*, Will Ridgeon used a 4K camera with a specially designed stand to get close to the brooding octopuses

BELOW Researchers study the Octopus Garden from the ROV control room aboard the *Western Flyer*

→ and ideally around the side so you can three-quarter backlight [the scene], so you don't get reflection off all the bits and pieces in the water," Ridgeon explains.

Those "bits and pieces" are marine snow – organic particles that constantly fall from shallower seas above. Marine snow is made of dead plankton and their faeces, stuck together with a microbial glue, and it's the main source of food for animals in the deep sea. But it makes filming difficult because films can look like they were shot in a blizzard.

To see through the blizzard and achieve the desired three-quarter backlight effect, the MBARI team built a lighting rig that the ROV could hold away from the camera and off to the side. "That's how we got some of these really fantastic shots," says Barry.

ACCELERATED DEVELOPMENT

As Barry's research and the BBC's filming progressed, the team made some startling discoveries. For one thing, there were never any medium-sized octopuses coming to the site, nor any signs of feeding. It was only ever fully grown, mature octopuses. They were coming here to reproduce and nothing else. It might be called the Octopus Garden, but the site is undoubtedly an octopus nursery.

The team also gathered evidence that the brooding females are using thermal springs at the site to speed up the development of their young. For octopuses, there's a strong relationship between temperature and hatching time; the colder it is, the longer it takes and the more dangerous it becomes, because there are scavengers waiting to feast on unborn, unguarded octopus eggs.

Temperature probes showed that the seawater surrounding each octopus nest could reach 10°C (50°F), far warmer than the 1.6°C (34°F) of the water just a few metres away.

By watching specific octopuses brooding at the site (individuals are recognisable by their patterns of scratches and scars), Barry and colleagues saw that their eggs take 1.8 years on average to hatch. The females don't move during that time, but are constantly batting away predators and safeguarding their clutch of around 60 eggs. "Once you plant your eggs on the rock, that's it – you're stuck with that site," says Barry.

At just under two years, it's not the longest octopus brood time. That record goes to *Graneledone boreopacifica*, a different species that other MBARI scientists found nearby, clinging to the side of

LEFT With a brood period of 4.5 years, the *Graneledone boreopacifica* (a species of octopus that hatches its eggs in colder waters) holds the record for the longest brood period of any animal

"BIOLOGISTS THINK THERE COULD BE LOTS MORE OCTOPUS NURSERIES OUT THERE"

Monterey Canyon at a depth of 1.4km (just under a mile). They saw one female brooding her eggs for 4.5 years – longer than any other animal on record. But she was rearing her eggs in water much warmer than the 1.6°C ambient temperature at the Octopus Garden. If it weren't for the thermal springs, it would likely take a decade or more for the Octopus Garden eggs to hatch.

When the site was discovered, biologists were astounded to find octopuses nesting there. Geologists, however, were fascinated by the warm water percolating up through the seabed, which had never been seen before.

The springs are much cooler than the searing hydrothermal vents that form at the edges of tectonic plates where new, molten seafloor is made. Temperatures around vents can be hundreds of degrees, although the immense pressure prevents the water from boiling. They were first discovered in the 1970s and are relatively easy to detect with temperature probes, because plumes of hot water rise hundreds of metres up the water column.

In contrast, thermal springs form away from these tectonically vigorous regions and, being much cooler, are more difficult to find. But geologists think there could be thousands of them and that they're likely to be highly stable, persisting in the same spot for hundreds, even thousands, of years. As such, biologists think there could be lots more octopus nurseries out there, established around these springs.

BIRTHS AND DEATHS

In the final scene of the 'Octopus Garden' episode of *Planet Earth III*, a cluster of tiny, suckered arms appears below a brooding female, then a bobble-headed young octopus swims off, like a mini-umbrella, into the darkness. More hatchlings follow and begin their lives in the ocean. Where they go, nobody knows… yet. "That's the next thing that I'd love to figure out," says Barry.

The hatchlings are big for octopus newborns, around 6cm (2in), giving them the best possible chance of surviving. But as anyone who's watched an octopus documentary before knows, this comes at an immense cost to the mothers. "These mums are fierce defenders of their brood, while they're just withering away," says Barry.

The fathers died years earlier, shortly after mating. On screen, we see the females' eyes glaze over and their bodies become wrinkled. Ridgeon saw what happens next, but decided it wasn't suitable for early evening TV audiences. The octopuses' corpses are immediately set upon by scavenging fish, snails, sea anemones and shrimp. →

BBC STUDIOS X2, ALAMY

"NOBODY KNOWS HOW FAR THE OCTOPUSES TRAVEL TO REACH THE GARDEN, OR HOW THEY FIND IT"

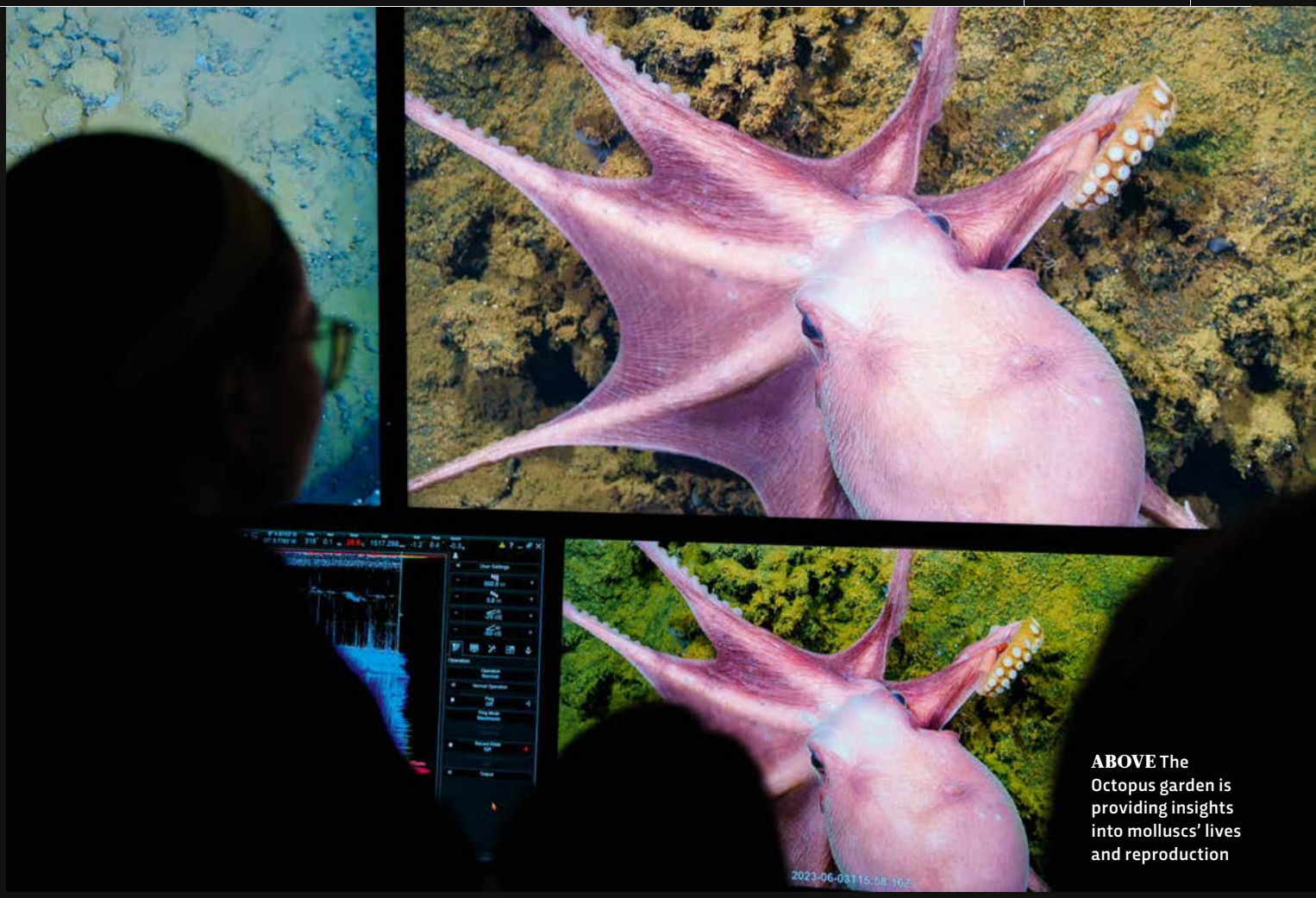
→ For Barry, this is another critical part of his findings at the Octopus Garden. The nesting season is asynchronous, with octopuses hatching and mothers dying throughout the year – roughly nine every day. The bodies of female octopuses help feed the rest of the ecosystem, supplementing the input of energy from marine snow by 72 per cent. "It's clearly a big food subsidy for the local ecosystem," says Barry. "It wouldn't be if it was in shallow water," he adds, because there's plenty of food around. But in the more barren deep sea, nothing goes to waste.

The BBC has finished filming at the Octopus Garden, but Barry's studies continue. One thing he's keen to know is how old the sea anemones are. These are the giant orange, flower-like animals that make the Octopus Garden look like a real garden. Barry has studied sea anemones that live for decades in the shallow coastal waters and suspects the deep-sea varieties could live for centuries, in stark contrast to the relatively short-lived octopuses. "They're like these sentinels that have just been sitting there while the octopuses are cycling through," he says.

There are plenty more questions Barry would like answers to. "Are the octopuses locked into this form of breeding in warm sites, or can they still breed elsewhere at cooler, ambient temperatures? Is there fidelity to a particular nest site? Do they come back to the site they were born?" he asks. Nobody knows how far the octopuses travel to reach the garden, or how they find it, although Barry suspects they smell the scent wafting from so many dead and dying octopuses. "We'll definitely keep going back," he says. **SF**

ABOVE Around 20,000 pearl octopuses were nesting in the Octopus Garden, making it the world's largest gathering of eight-armed molluscs

by **DR HELEN SCALES** *(@helenscales) Helen is a marine biologist, broadcaster and science writer. She is the author of* Spirals in Time *and* The Brilliant Abyss.



ABOVE The Octopus garden is providing insights into molluscs' lives and reproduction

Octopus nurseries

To date, there are four known deep-sea octopus nurseries, all of them in the Pacific Ocean

MONTEREY BAY AQUARIUM RESEARCH INSTITUTE, BBC STUDIOS, OCEAN EXPLORATION TRUST/NOAA

ABOVE Heat from the thermal springs at the Octopus Garden help the eggs develop and hatch

DORADO OUTCROP

COSTA RICA

FOUND: DECEMBER 2013

Researchers from University of Akron in Ohio, the Field Museum in Illinois, and the University of Alaska Fairbanks observed more than 100 octopuses, 160km (100 miles) off the Pacific coast of Costa Rica and 3km (1.8 miles) underwater. The octopuses appeared to be an undescribed species of *Muusoctopus*. None of the eggs seemed to be growing.

OCTOPUS GARDEN

NEAR DAVIDSON SEAMOUNT

FOUND: OCTOBER 2018

While exploring a hillock 3.2km (2 miles) down and 12km (7.5 miles) southeast of Davison Seamount, researchers from the National Oceanic and Atmospheric Administration's (NOAA) Monterey Bay National Marine Sanctuary, in California, and collaborators including the Ocean Exploration Trust, found thousands of brooding pearl octopuses (*Muusoctopus robustus*). Their eggs were viable and in various stages of development.

OCTOCONE

17KM (10.5 MILES) NORTHEAST OF OCTOPUS GARDEN

FOUND: OCTOBER 2019

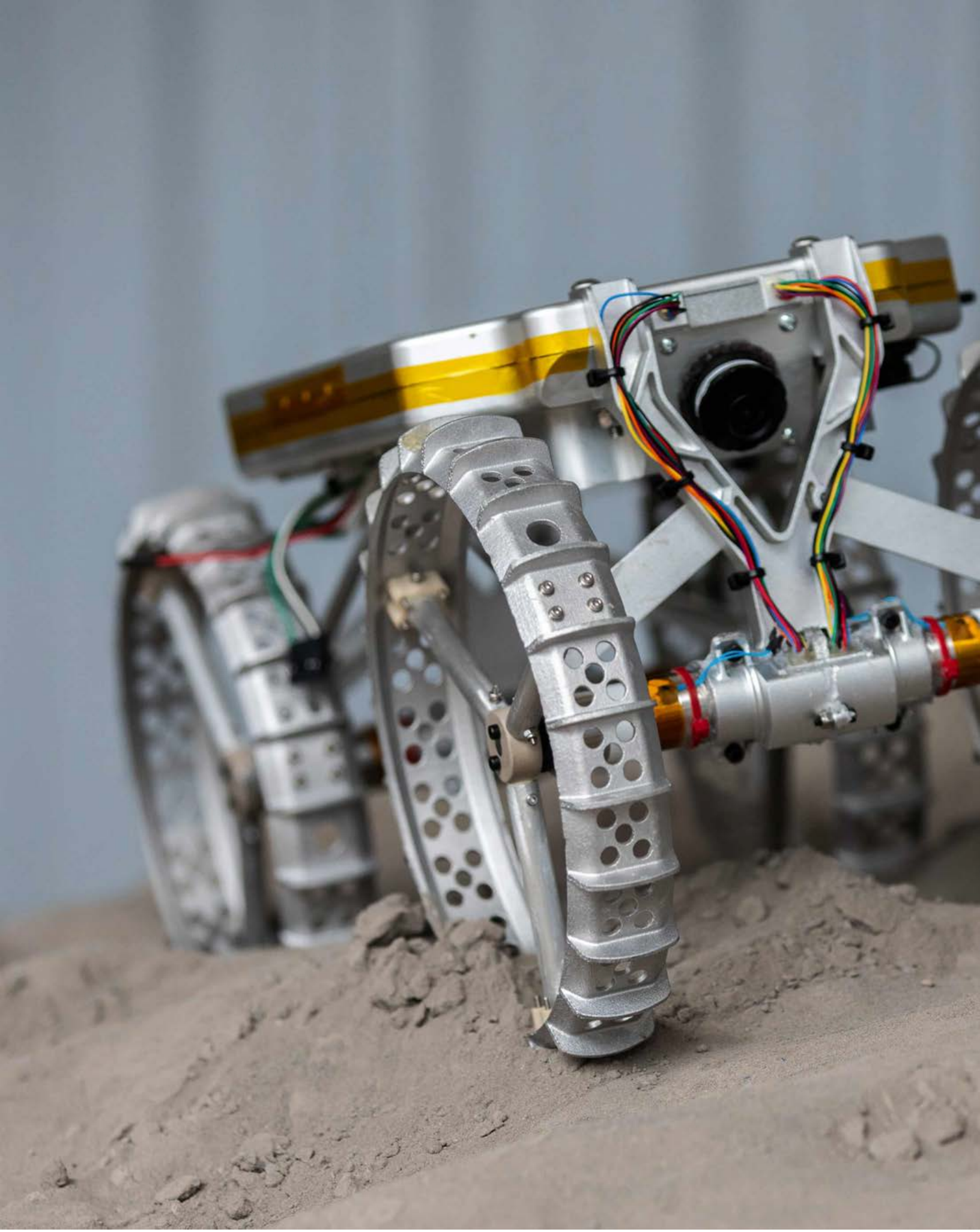
Researchers from NOAA and collaborators including the Ocean Exploration Trust observed a second aggregation of pearl octopuses (*Muusoctopus robustus*), again brooding viable eggs, on a volcanic cone east of Davidson Seamount.

UNNAMED SEAMOUNT

COSTA RICA

FOUND: JUNE 2023

Researchers from the Bigelow Laboratory for Ocean Sciences and the University of Costa Rica observed an octopus nursery off the Pacific coast of Costa Rica, on an unexplored and still unnamed seamount. This may be the same undescribed species of *Muusoctopus* that was found at the Dorado Outcrop. In light of this, the research team also returned to the Dorado Outcrop and found the females' eggs were alive and growing, indicating that it is, in fact, an active octopus nursery.



NASA/KIM SHIFLETT

Astrobotic's CubeRover undergoes testing in the regolith pit at NASA's Kennedy Space Center

HOW TO MAKE THE MOON ON EARTH

The expense and prestige involved in sending landers and rovers to the Moon means you can't afford for them not to work when they get there. But the lunar landscape is like nothing here on Earth. So how, and where, do you test equipment that's bound for the Moon?

by DR EZZY PEARSON

ABOVE Low-angled lighting simulates the Sun in one of the testbeds at NASA's Ames Research Center in California

Nighttime in the Mojave Desert. The stars of the Milky Way turn slowly above a landscape so dark you can barely make it out. Suddenly, spotlights switch on. They're angled low to the horizon and off to one side, but spill light across a pale grey, undulating terrain that's pockmarked by craters. You know you're standing among the sands of California, but lit like this, it looks like you're on the Moon.

This 'Moon in the Mojave' is the work of spaceflight company Astrobotic, which has been building the Lunar Surface Proving Ground (LSPG). The 100m^2 (approx 1,000ft^2) site has been made to look exactly like the lunar south pole. The region was ignored by early Moon explorers, but has witnessed a surge in interest over the last decade after signs of water ice were found in the permanently shadowed recesses of deep craters. Such water could be an invaluable resource both for science and future explorers.

Astrobotic aims to head to the region with its Peregrine and Griffin landers, due to launch this December and then November 2024 respectively. They're just two of a great many missions supporting NASA's Artemis programme to return humans, including the first woman and person of colour, to the lunar surface by the end of the decade. But before either Peregrine or Griffin can even think of leaving the ground, they have to be fully tested.

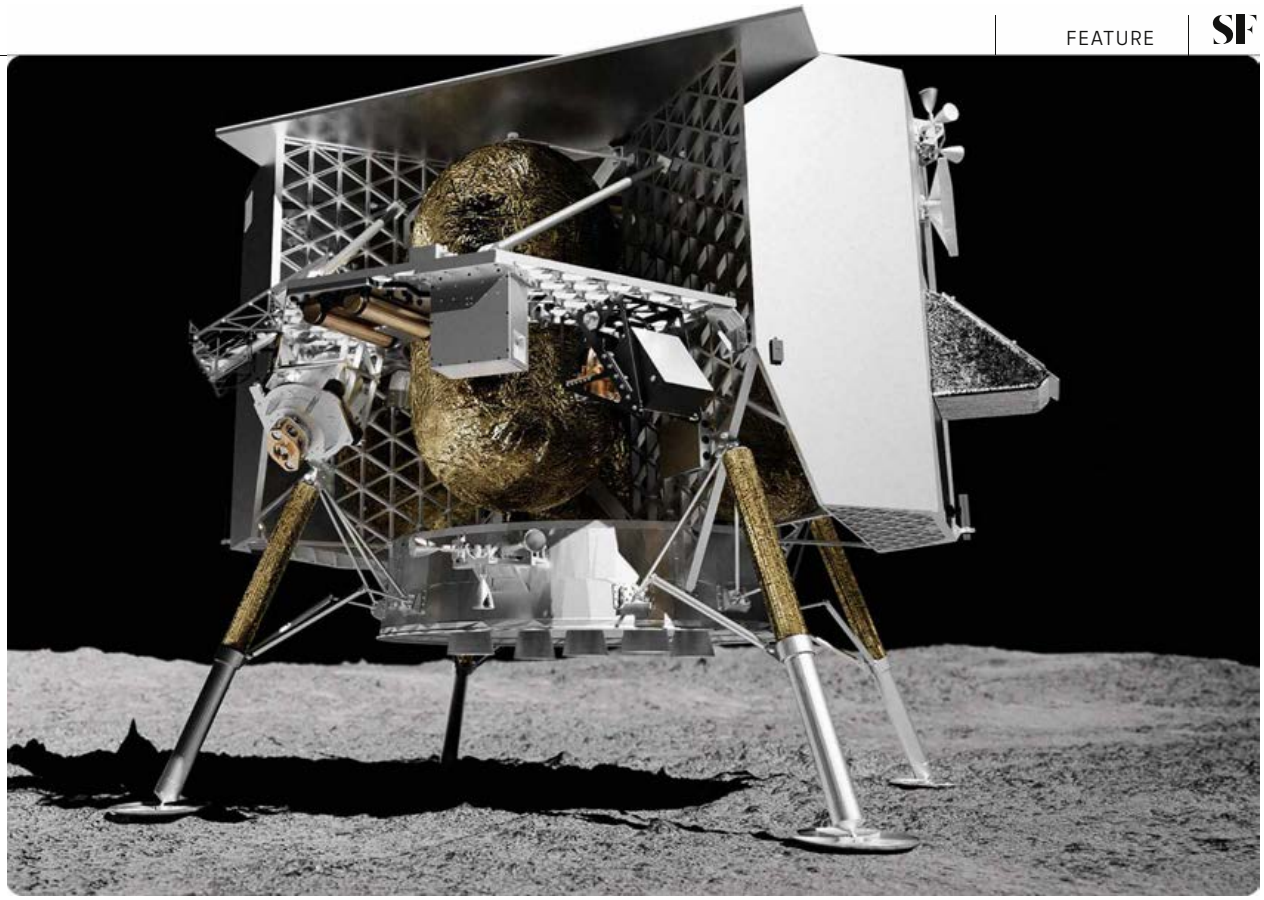
MIMICKING THE MOON

"We do everything we can to simulate the lunar and space environment on Earth before we send our spacecraft off, because you can't practise in space," says Alivia Chapla, director of marketing at Astrobotic. "Once you send the spacecraft out, it's out there. For robotic missions, you can't fix or touch it once it leaves this planet." As such, tests are vital for working out any potential problems while they can still be fixed. But when your vehicle is bound for a landscape unlike any on Earth, performing these tests isn't easy.

"ONE OF THE BIGGEST CHALLENGES FACING LANDERS AND ROVERS AT THE LUNAR SOUTH POLE IS LIGHT"

The Soviet Lunokhod robotic rover and the Apollo human-driven rover were both designed and built in the 1960s, before anyone really knew what the lunar surface was like. Both were tested on Earth, but when the Soviet drivers of Lunokhod-1 first took to the rover's remote controls, it was obvious these rehearsals were woefully inadequate. With no atmosphere or colour on the Moon to provide a sense of depth, it's difficult to

NASA/AMES X2, ASTROBOTIC



TOP The Astrobotic Peregrine lander

ABOVE A shadowy crater at the Ames Research Center

interpret the topography of the landscape at the best of times, but the Lunokhod-1's black and white cameras also removed any subtlety that might have made it easier.

Unlike the Soviets of the 60s, Astrobotic has been able to accurately scan the area it plans to land on, allowing the company to recreate the topography at the LSPG.

"The LSPG mimics the look and feel of the Moon," says Chapla. "We're making it from a light grey, highly reflective, thin layer of stucco [or render, a construction material made of aggregate, a binding agent and water] to mimic the lunar surface."

Astrobotic will be able to fly test builds of its guidance cameras and ranging equipment over the LSPG, or even train its drivers on how to navigate across it to make sure they're fully prepared to tackle the lunar south pole.

THE LIGHT FANTASTIC

Trivial as it might sound, one of the biggest challenges facing landers and rovers at the lunar south pole is light. The Sun comes in low to the horizon, somewhere between 5-10°, creating long shadows. It means there are shaded corners in and around craters that have been dark for billions of years, which is how water has been able to survive on the lunar surface for so long. But these same shadows also make it very difficult to see the landscape clearly.

Because the LSPG is so large, it needs to be outside, meaning there's only one way to simulate lunar lighting conditions. "We actually do a lot of our testing at night. We simulate extreme lighting with different spotlights. We'll simulate the light coming from the Sun [and] we'll simulate Earth's glare, depending on what we're looking at," says Chapla.

The LSPG's solid stucco surface emulates the roughness of the lunar surface visually, but what it fails to recreate is how it feels. The real Moon is covered in fine dust. This regolith, as it's known, was formed over billions of years by meteorites, large and small, striking the surface and grinding up the rock there.

You wouldn't have to travel far from Astrobotic's LSPG to find a simulated lunar landscape with realistic dust, though. Located in nearby Silicon Valley is NASA's Ames Research Center, home to the Lunar Lab and Regolith Testbeds. Here, you'll find two windowless rooms with walls that are painted black so that they're utterly dark when the lights are off. In the middle of each →

LEFT A researcher at NASA's Kennedy Space Center, Florida, creates a fine spray of Moon dust simulant. The powder can easily be breathed in and is known to cause lung irritation, so protective clothing is worn while handling the substance

NASA/KIM SHIFLETT, ARNOLD REINHOLD/WIKIPEDIA, NASA/KSC

"IT'S NOT UNLIKE CRAFTING A FINE PIECE OF PASTRY. YOU SHAPE THE CRATERS THEN SPRINKLE SIMULANTS"

→ room is a giant sand box filled with 20 tonnes of fake Moon dirt.

The simulated regolith in the older of the two labs is the same dark grey as the lunar mare – the dark patches visible on the Moon's face. The set-up in the newer lab, however, better resembles the bright landscape of the lunar south pole.

Just like at Astrobotic, spotlights mimic the low Sun at the lunar pole, but here the light plays strangely on the surface. The dust grains act like tiny reflectors, shaping the light in strange ways that can confuse cameras and computers trying to interpret the terrain. NASA engineers are able to craft craters, mounds or any other shape into the testbeds, allowing them to pit their navigation systems against the obstacles to see how they fare in the unusual lighting.

"It's not unlike crafting a really fine piece of pastry," says Dr Terry Fong, Ames's chief roboticist. Currently, he's part of the team developing and building the Volatiles Investigating Polar Exploration Rover (VIPER) that NASA hopes to send to the lunar south pole by 2024 to analyse the potential resources that might be found there. "[We] shape the craters, we'll put in small rocks, but then we'll take a handful of simulants and sprinkle it across the top. As it hits, it creates all these little pockmarks all over the surface. It's very labour intensive, but it's somewhat artistic."

But visual systems aren't the only aspect of a rover that need to be tested. This is why there are many other such regolith bins, including one at Astrobotic, as well as at the Simulated Lunar OPErations Lab (SLOPE) at NASA's Glenn Research Center in Ohio. These might not resemble the Moon as closely, but instead they allow teams to test how the dust behaves.

"A big concern we have is, 'can the rover get stuck?'" says Fong. "It's a wheeled rover going to a place we've never been before. We've put VIPER into a variety of configurations – different angles, obstacles, loose and hard-packed soil."

During several of these tests, the rover did indeed get stuck. Which, counterintuitively, was actually a good thing, as it not only helped shape the rover's design to reduce the chances of it getting stuck on the Moon, but also allowed the operators to develop new techniques that would help them work the rover free if it did.

"VIPER has active suspension and one of the things we can do is independently lift up each wheel," says Fong. "We can [make VIPER] 'swim' – like a breaststroke – through the soil."

A DUSTY BUSINESS

The regolith bins are usually surrounded by clear plastic sheets, as a rover trying to dig itself out often flings a lot of dust around. It's important to keep the dust contained, as lunar regolith has a long history of getting everywhere.

Recalling his time on the Moon, astronaut Buzz Aldrin said: "The more time you spend there, the more you get covered from helmet to boots with lunar dust."

The Apollo astronauts encountered quite a few problems with dust. The fine powder was easily breathed in, causing lung irritation (and even an allergic reaction, in the case of

MAKE YOUR OWN MOON DUST

For now, Earth rocks must serve as a stand-in for the real thing

Though the Apollo missions brought back an impressive 382kg (842lbs) of Moon rock, this isn't nearly close to the 20 tonnes needed to fill a regolith bin. Instead, lunar analogue facilities use a specially made simulant regolith. When making it, the first step is to find rocks on Earth that are the closest match to those found on the Moon.

"Fifteen years ago, lunar simulant was typically something called JSC-1A," says Greg Schmidt, director of the Solar System Exploration Research Virtual Institute (SSERVI) at Ames Research Center. This simulant is made from glass-rich volcanic rock known as basalt, gathered from the Merriam Crater near Flagstaff, Arizona as its mineralogy closely matches the rocks brought back by Apollo 14. "It's dark grey in colour and a really good simulant for the mare – the dark areas on the Moon."

JSC-1A fills one test bed at Ames; the other is filled with LHS-1, a simulant made of anorthosite from the Stillwater Mine in Montana, which is a better match to the lunar highlands of the Moon's south pole. "When we got the pure anorthosite, it was so bright that we realised we needed to mix in a little bit of basaltic glass to make it more like what we actually see," says Schmidt.

For mechanical testing, where a perfect chemical match isn't as important, there are other simulants made from more readily available rock, meaning they can be produced in bulk more cheaply. These base rocks are ground down and sifted into several grades, from fine to coarse.

What simulants don't recreate, however, is the smell – moon dust is odourless. And yet, all of the Apollo moonwalkers reported that the real lunar dust smelt of "spent gunpowder".

"It was like burnt charcoal," said Buzz Aldrin. "Similar to the ashes that are in the fireplace, especially if you sprinkle a little water on them."

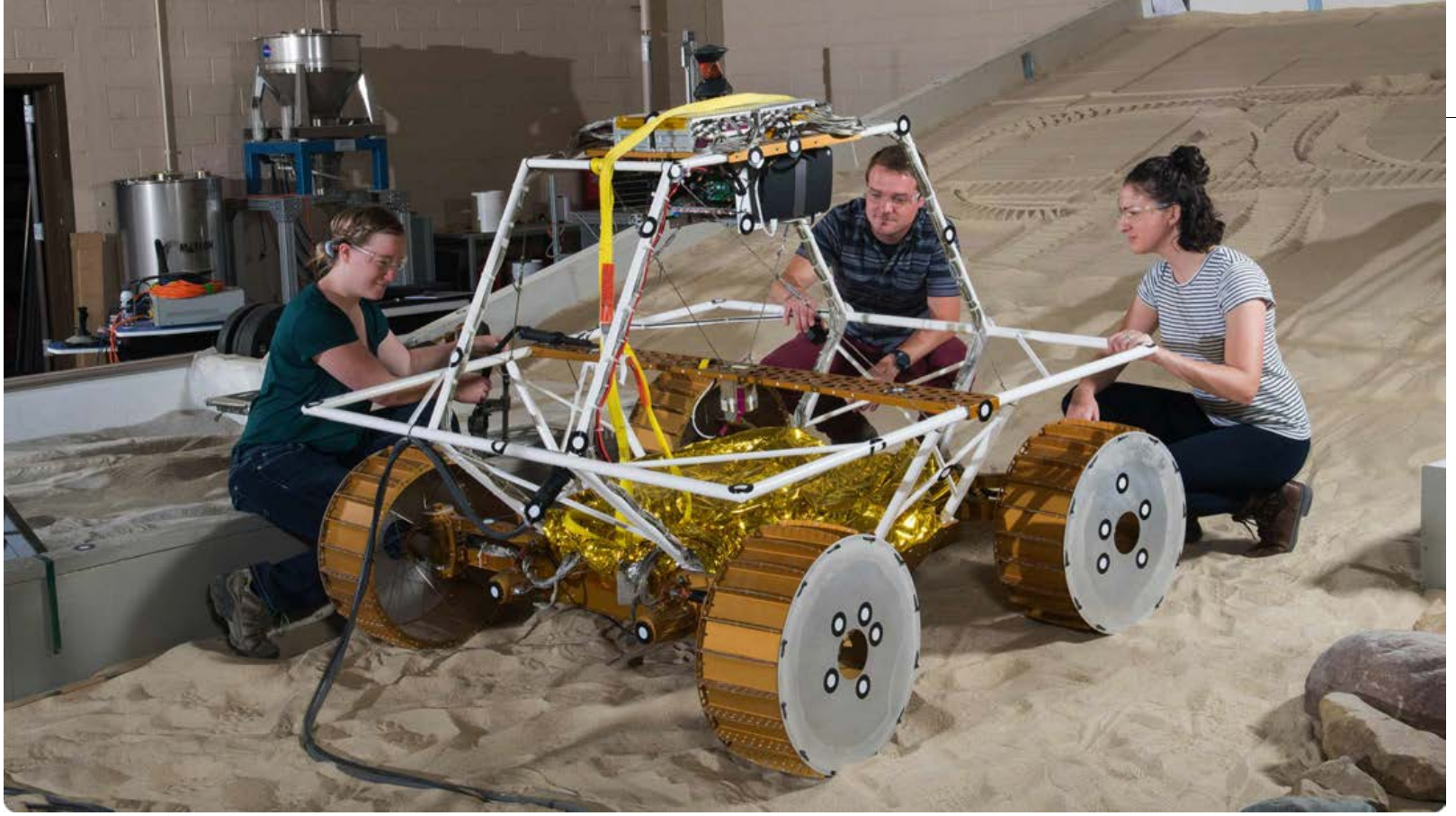
Apollo 17's Harrison Schmitt). The dust also affected the non-human components of the mission. It was so abrasive it ate into spacesuits and gummed up the joints on equipment. The problem grew worse when the later missions arrived with the lunar rover, which kicked up huge 'rooster tails' of dust as it traversed the landscape.

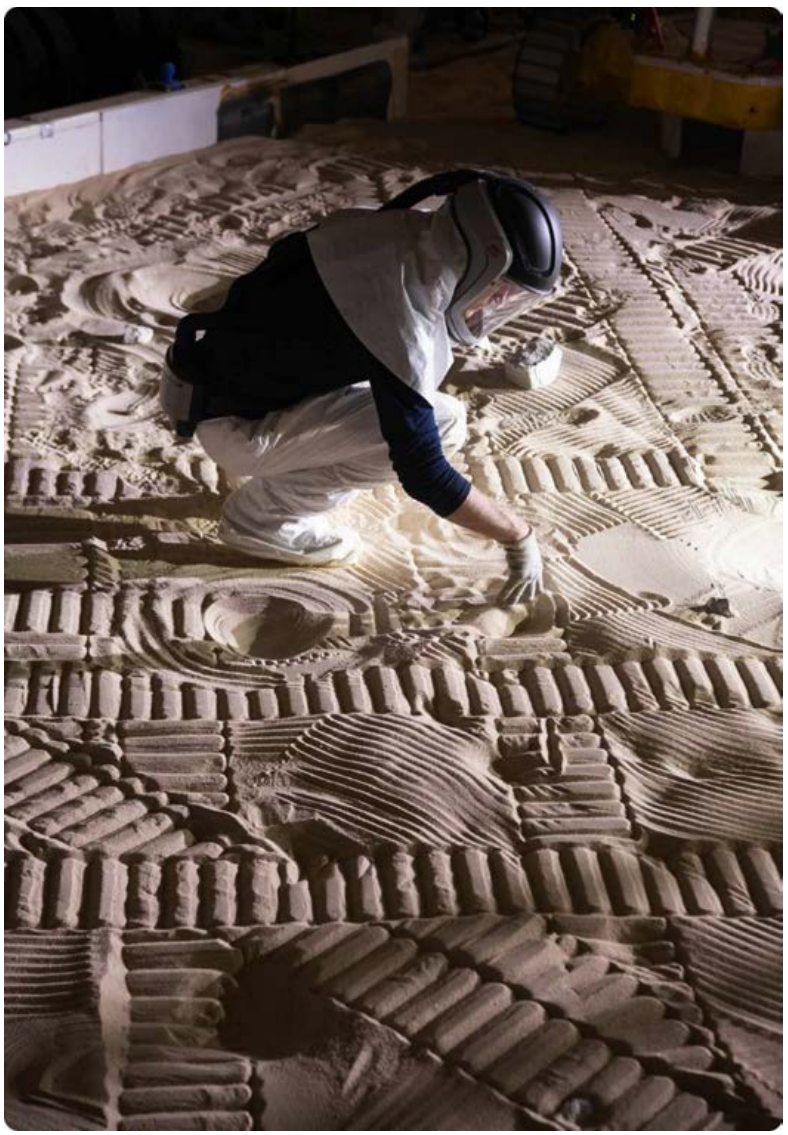
"By the middle or end of the third EVA [extra vehicular activity], simple things like bag locks and the lock that held the pallet on the rover began to not only malfunction, but to not function at all," said Apollo 17 astronaut Gene Cernan in his post-mission debrief. "You're continually fighting the dust problem, both outside and inside the spacecraft."

The reason for lunar dust's hazardous properties becomes immediately obvious when you see it under a microscope. "If you look at lunar dust – the real stuff – you see these very jagged, tiny pieces of lunar material," says Greg Schmidt, the director of the Solar System Exploration Research Virtual Institute (SSERVI) at Ames.

Earth-made simulants aren't quite as bad as genuine regolith, as natural weathering has blunted their edges, but they're still fine enough to breathe in. "When you're changing the surface, such as putting →

ABOVE Astronaut Gene Cernan, the Apollo 17 commander and last person to walk on the Moon, sits in the lunar module covered in lunar dust in 1972. He famously commented on how difficult it was to contend with the very fine and abrasive dust





LEFT Parabolic flights are one method used by engineers to mimic the low-gravity conditions on the lunar surface

ARTIFICIAL GRAVITY

With no artificial gravity generators available yet, space explorers have to improvise…

The different gravity of the Moon is one of the most difficult things to simulate when it comes to testing lunar equipment.

"We care a lot about that because the gravity on the Moon is one sixth that of Earth," says Dr Terry Fong, director of the Intelligent Robotics Group (IRG) at Ames Research Center. "In terms of a wheeled rover like the Volatiles Investigating Polar Exploration Rover (VIPER), you worry how it will drive – if you hit a bump, will the whole vehicle jump?"

It's impossible to change Earth's gravity, so engineers have developed a variety of creative methods to emulate the Moon's reduced gravity as best they can. One of the most famous methods is by using parabolic flights, which sees stripped-out passenger planes fly at sharp ascent and descent angles to produce the illusion of reduced gravity. It's not ideal though, as each arc only offers 10-20 seconds testing time and you can't use a regolith bin unless you want the entire cabin to be filled with simulant dust.

If you want to simulate lunar gravity while also using a fake terrain, there are other techniques. One method, used to test the Apollo rovers in the 1960s, is to build a test vehicle that has the same driving systems that your flight model will have, but with everything else stripped out so it's one sixth the mass.

"Another thing you can try is gravity off-set," says Fong. "It's where you use a crane or, if it's a small rover, a large helium balloon (have you seen the movie *Up*?) to reduce the effective mass."

One thing neither of these methods manage to do, however, is reduce the mass of the actual dust particles. The only way to tell how that might affect a rover will be to see what happens when it gets to the Moon.

"IT'S IMPOSSIBLE TO RECREATE THE MOON'S GRAVITY, WHICH IS ONE SIXTH THAT OF EARTH"

LEFT, CLOCKWISE FROM TOP The VIPER rover in a testbed at the Glenn Research Center, Ohio; testing the VIPER's maneuverability; the Simulated Lunar Operations Lab; rocks are positioned during VIPER testing

NASA/GLENN RESEARCH CENTER, ALAMY

by **DR EZZY PEARSON**

Ezzy Pearson is the features editor of BBC Sky at Night Magazine. *Her book* Robots in Space *is out now (£20, The History Press).*

→ in a simulated crater, you want to wear protective gear. But once that's settled, it's actually okay to be in the same room," says Schmidt.

Even with all these regolith bins, there are some aspects of lunar exploration that are far more difficult to emulate. It's impossible to recreate the Moon's gravity, which is one-sixth that of Earth's, though the engineers have found some clever tricks to fake it (see 'Artificial Gravity', right).

Another big concern is radiation, but current radiation testing facilities are only large enough to test individual components, not entire rovers. Size is not a problem when it comes to testing how rovers fare in a vacuum, though – NASA has some of the largest vacuum chambers in the world. Yet, while it might seem like a simple matter to set up a regolith bin inside of one, the truth is that the dust thrown around in the process would destroy the chambers' delicate valves and seals.

"Ideally, we would like to have as many factors be as close as possible to the actual environmental conditions," says Fong. "But the reality is that we have great difficulty trying to do that all at the same time."

Indeed, there won't be any way to test every aspect of a lunar vehicle until it's on the surface. NASA's long-term plan is to set up a research base on the Moon, so perhaps one day future explorers will be able to test their designs on the real surface. Until then, they'll have to make do with the little pieces of makeshift Moon – like Astrobotic's LSPG and NASA's regolith bins – that can be found right here on Earth. **SF**

The Power of Caffeine

For many, caffeine is considered a guilty pleasure. But there is growing evidence that our daily fix isn't necessarily a bad thing. In fact, it might actually be doing us some good

by DR ANDY RIDGWAY

Caffeine has been getting a bad rap recently. Whether it's highly caffeinated energy drinks making it difficult for kids to concentrate in class, or too many teas and coffees during the day leaving us unable to sleep at night, caffeine, in many people's eyes, is a cause for alarm. As such, the general advice regarding caffeine consumption increasingly seems to be to cut back on it, or cut it out altogether.

But it's not as if caffeine is entirely without merit. There's no denying it's a psychoactive substance. Or, to put it more bluntly, caffeine is a drug (the world's most widely consumed drug, in fact – chances are, you're under its influence right now). But, like many drugs, in the right dose, it has benefits. It was the clarity and energy that doses of caffeine provided (distributed via the tea and coffee houses of Europe) that helped usher in the Enlightenment and make the switch from farms to factories during the industrial revolution.

But dosage is the key variable. And although coffee and tea have been providing us with a tasty pick-me-up for centuries, nowadays more of us are consuming caffeine in much higher concentrations due to the boom in energy drinks and tablets. This has prompted a rise in research into caffeine, as scientists work to better understand its effects on us and the mechanisms by which it produces them.

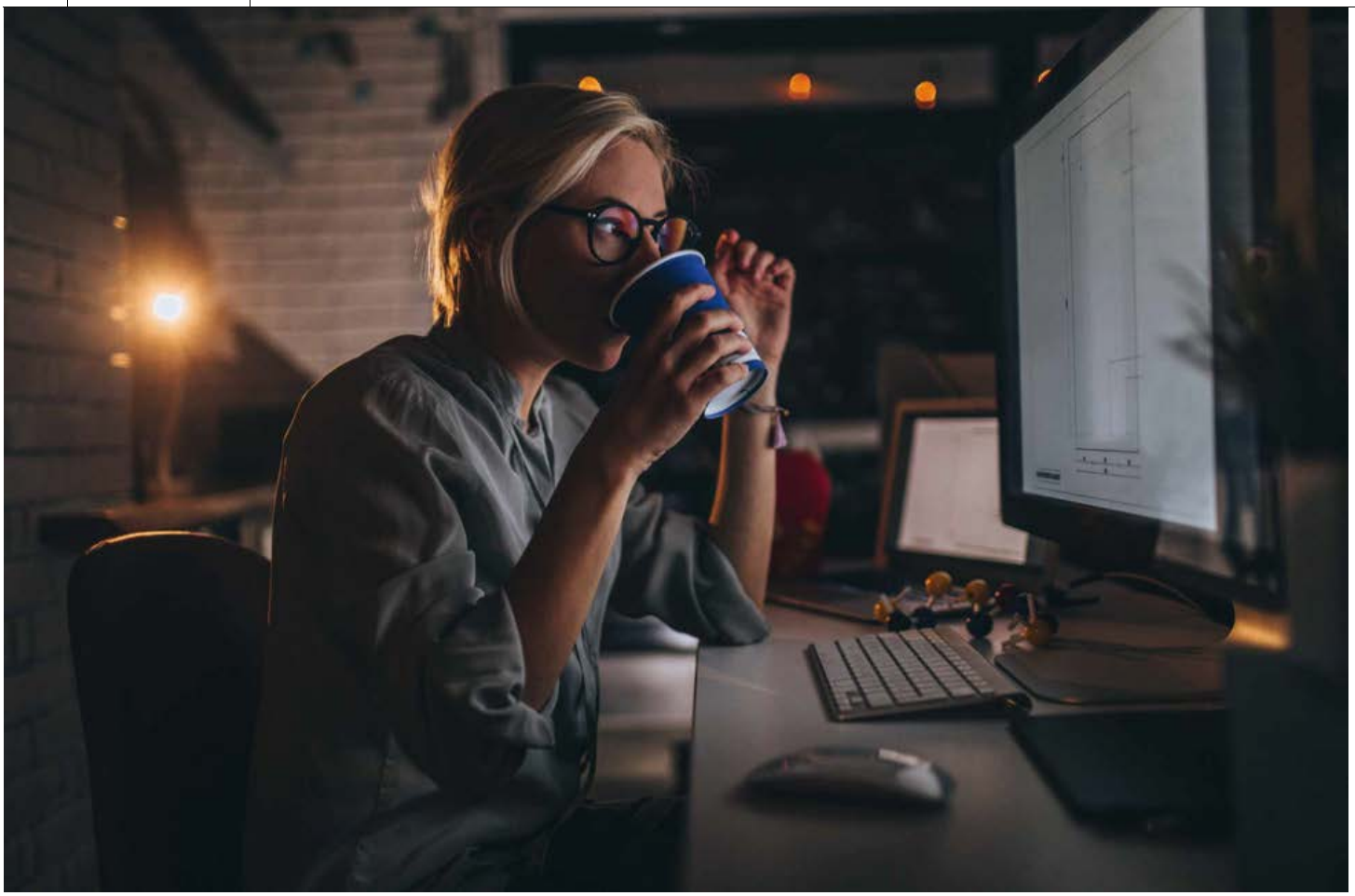
So what are we learning from all this research? For one thing, just how differently each of us processes and reacts to caffeine. But perhaps more importantly, it's providing evidence that as well as perking us up in the morning, a few cups of coffee or tea each day might also help us stave off illnesses, such as diabetes and certain forms of cancer. So does caffeine really deserve its bad reputation?

THE DOSE MAKES THE POISON

Anyone who consumes caffeine every day knows the importance of dosage: how much to take and when to take it. Get the dose right, and caffeine can lift your mood and make you more alert; overdo it and you risk anxiety, tremors and disrupted sleep. Both the US Food and Drug Administration and the European Food Safety Authority say that a daily caffeine intake of 400mg (about two to three mugs of filter coffee, depending on the size of the mug) won't cause problems for healthy adults. →

"AS WELL AS PERKING US UP IN THE MORNING, A FEW CUPS OF COFFEE OR TEA EACH DAY MIGHT ALSO HELP US STAVE OFF ILLNESSES SUCH AS DIABETES"

ILLUSTRATION BY RAMON AVELINO/PATSWERK



→ As for when to take caffeine – or rather, when to stop taking it in order to prevent it from effecting your sleep, that depends on how you administer it. Researchers in Australia and the UK published a study in the journal *Sleep Medicine Reviews* earlier this year that tried to give clear guidance on when your last 'dose' of caffeine should be. According to their report, you should drink your last tea or coffee 8 hours and 48 minutes before you go to bed. If, however, you use a pre-workout caffeine supplement, which typically has double the caffeine of a cup of coffee, that should be taken no later than 13 hours 12 minutes before bedtime.

The problem with giving definitive directions on how much caffeine is okay and when to stop consuming it, however, is that some of us are more sensitive to it than others. How long it hangs around inside our bodies varies, too – caffeine has a half-life (the time required for a substance to lose half of its initial effectiveness) of 3-7 hours in adults.

The reason for this is genetic. But to understand it, you first need to know what caffeine does inside your body.

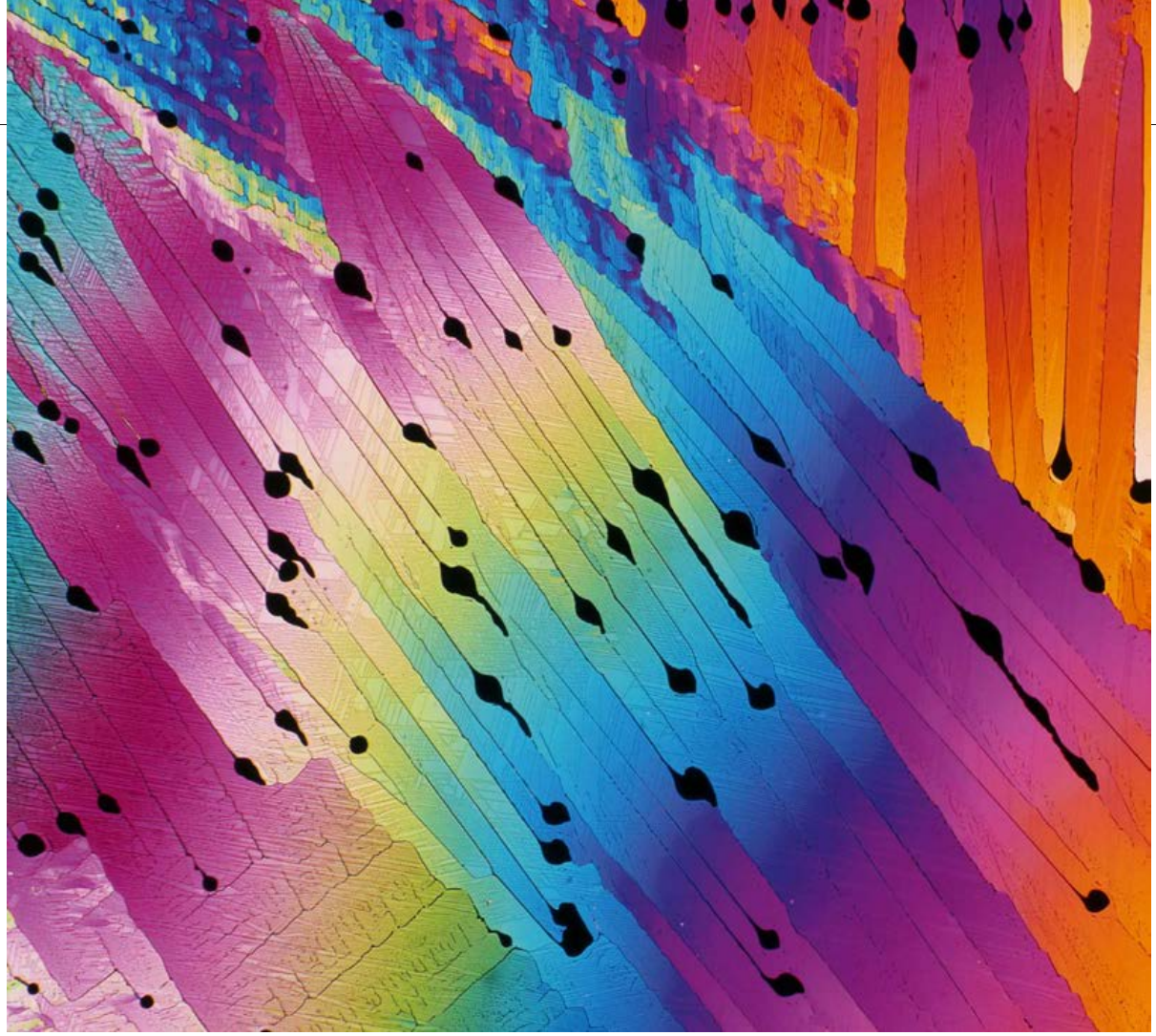
"PART OF THE INDIVIDUAL DIFFERENCES IN HOW WE RESPOND TO CAFFEINE IS DOWN TO THE EXTENT TO WHICH EACH OF OUR BODIES HAVE ADAPTED TO IT"

CAFFEINE AND GENES

During the day, a molecule called adenosine builds up in your brain. Adenosine binds with receptors on nerve cells, or neurons, slowing down their activity and making you feel drowsy. But caffeine is also able to bind with these receptors, and by doing so it blocks adenosine's effect, making your neurons fire more and keeping you alert.

Caffeine also activates the pituitary gland at the base of your brain. This releases hormones that tell the adrenal glands on your kidneys to produce adrenaline, causing your heart to beat faster and your blood pressure to rise.

GETTY IMAGES, SCIENCE PHOTO LIBRARY, UNIVERSITY AT BUFFALO



LEFT This polarised light micrograph image reveals the crystalline structure of caffeine

ABOVE Prof Jennifer Temple researches the effects of caffeine

TOP LEFT Caffeine's effects enable us to shake off our natural circadian rhythms, if we need to be awake and alert when we'd normally be asleep

If, however, your daily caffeine intake is consistent, your brain will adapt to it.

"Your brain is like, 'Okay, every morning I'm getting this caffeine that's binding to these receptors and blocking adenosine from binding to them'. And so [your brain] creates extra receptors to give adenosine more of an opportunity to bind with them and have its usual effect," says Prof Jennifer Temple, whose lab at University at Buffalo in New York, carries out research on the effects of caffeine. "And more adenosine is also produced to counteract the caffeine. That's why it takes more and more caffeine to have the same effect."

These adaptations take place rapidly – within as little as a week.

Part of the differences in how we respond to caffeine is down to the extent to which each of our bodies have adapted to it. But then there's also the effect of our genes. Caffeine is mainly broken down, or metabolised, by the CYP1A2 enzyme in the liver, and the gene that codes for that enzyme has been found to vary a lot between people.

Research shows that, for the most part, it's the version of the CYP1A2 gene you have that determines how quickly you can metabolise caffeine and therefore how long it hangs around in your body. Fast metabolisers are able to clear caffeine quickly, so the effect of an espresso wears off faster for them. The adenosine receptors in the brain also vary a lot depending on a person's genetic make-up. And there are also some variants of the ADORA2A gene, which encodes one type of adenosine receptor, that make people particularly sensitive to caffeine.

It's also our genes that influence how much caffeinated coffee and tea we drink each day. "Coffee is naturally a bitter substance and so it's interesting →

→ how such a bitter beverage has become so popular," says Marilyn Cornelis, Associate Professor of Preventive Medicine at Northwestern University in Illinois who researches the links between genes and caffeine. "Based on evolution, we should naturally avoid bitter foods – it's a protective effect your body has to avoid poisonous things."

ABOVE Caffeinated energy drinks are enormously popular, but the amounts of caffeine, as well as the blend of other ingredients they contain, can vary a lot between brands

"COFFEE IS NATURALLY A BITTER SUBSTANCE AND SO IT'S INTERESTING HOW SUCH A BITTER BEVERAGE HAS BECOME SO POPULAR"

It's therefore logical to assume that people who are less sensitive to bitter tastes will be the ones who drink more coffee. But that's not the case.

A study led by Cornelis and published in *Scientific Reports* shows that the version of the CYP1A2 gene we have influences how much coffee we drink to a much greater extent than our sensitivity to bitter tastes. People with the version of CYP1A2 that makes them fast metabolisers drink more coffee. And tests show fast caffeine metabolisers have lower caffeine levels in their blood. "It suggests that they're metabolising caffeine so quickly, [that] they're consuming more coffee to get the stimulant effects we equate with caffeine," says Cornelis.

But whether you're a fast caffeine metaboliser or not, chances are you're pretty good at moderating your caffeine intake. "The data suggests that, whether they're conscious of doing it or not, people do a really good job of adjusting their caffeine intake to hit their sweet spot," says Temple. "Because when they go over it, the effects are unpleasant and there's a memory of that, so they go back to their sweet spot."

That perfect balance of caffeine intake is potentially harder to gauge with caffeinated energy drinks, though. Studies show that the top-selling caffeinated energy drinks in the UK and US contain 75-160mg of caffeine. But research published in *Drug and Alcohol Dependence* reported that some contain as much as 500mg of caffeine. By comparison, a 240ml mug of filter coffee contains about 190mg. The varied caffeine levels →

GETTY IMAGES X2

DO YOU HAVE A CAFFEINE PROBLEM?

For habitual caffeine drinkers, mornings often begin with a lethargic, fuzzy and blunt feeling, as well as – on the worst days – a dull headache. The one thing that will sharpen you up, get you thinking clearly and shift that thump in your head is a steaming-hot cup of tea or coffee. But does that overriding need for a caffeine hit first thing in the morning mean you're addicted to it? The answer to that question depends on how you define addiction.

"There are a lot of criteria surrounding a diagnosis of addiction or substance use disorder that are to do with the illicit nature of it," says Prof Jennifer Temple, at the University at Buffalo, New York. "Are you using this substance at the expense of work or at the expense of spending time with your family, and are you going to great lengths (possibly illegal ones) to obtain this substance? It's hard to get caffeine to fit the diagnostic criteria for addiction we use with other substances."

How caffeine effects our brains also differs to the substances we typically associate with addiction. "Most drugs that can be abused directly bind to dopamine receptors, or they're inhibiting dopamine re-uptake," says Temple. "They're acting directly on the reward centres of the brain, and caffeine doesn't act like that."

Temple says she would describe caffeine as habit forming, rather than addictive. "For the lay person who's not a scientist studying reward and reinforcement, it's addiction in the colloquial sense that they're thinking about with regard to caffeine. So, people feel like they need to have caffeine and when they don't have it, they feel bad. Part of that is because caffeine has a pretty short half-life, so you wake up the next day and it's out of your system."

Temple, a neurobiologist, has a pragmatic approach to her own caffeine intake. "I used to stop drinking caffeine at noon. I would maybe have a cup of tea, but would stop drinking coffee. But I have a kid who is a serious hockey player and in the last year I've found myself getting a coffee when I'm in a rink [regardless of] what time of day it is."

Exactly what can be considered a caffeine problem is something that researchers have been wrestling with for years. In the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders*, widely used in the US for diagnosis, the American Psychiatric Association proposed a set of criteria for caffeine use disorder. These are:

1. A PERSISTENT DESIRE OR UNSUCCESSFUL EFFORT TO CONTROL CAFFEINE USE.

2. CAFFEINE USE DESPITE HAVING A PERSISTENT OR RECURRING PHYSICAL OR PSYCHOLOGICAL PROBLEM LINKED TO CAFFEINE.

3. WITHDRAWAL SYMPTOMS WHEN CUTTING INTAKE.

Based on this set of criteria, studies indicate 10-13 per cent of adults have caffeine use disorder.

If you think your caffeine use is a problem, research on quitting caffeine shows that gradually reducing your intake is the way to go. Stopping your caffeine consumption abruptly can lead to withdrawal symptoms that can be quite severe. In a Norwegian study published in *Frontiers in Neurology* in 2020, several migraine sufferers encountered severe migraines after they stopped drinking caffeine abruptly, instead of gradually cutting down.

Research published in the journal *Drug and Alcohol Dependence* in 2020 identified 'tapering' (progressively cutting back on caffeine over 4-6 weeks) as a way to reduce or stop caffeine consumption while avoiding withdrawal symptoms. In one study, published in the *Journal of Consulting and Clinical Psychology* in 2016, participants were asked to reduce their caffeine intake to 75 per cent of their normal level in week one, 50 per cent in week two, 25 per cent in week three and 12.5 per cent in week four. The participants who followed the tapering guidance were still consuming reduced levels of caffeine a year after the end of the tapering-off period.

→ in different energy drinks can make judging your caffeine intake tricky. But the complicating factors don't end there.

"Energy drinks contain other ingredients that interact with the caffeine in a way that we're still trying to understand because we don't know what they are," explains Temple. "All these blends are proprietary and so we don't know the exact formulation. But people respond differently. [So] we're studying the effects of energy drinks in the same way we've been studying coffee and caffeine systematically," she says.

ABOVE Due to its effects, caffeine is seen as a legal performance enhancer by many athletes, particularly those in endurance sports

> "THERE HAS ALSO BEEN A RAFT OF STUDIES ATTEMPTING TO DETERMINE HOW CAFFEINE BOOSTS OUR COGNITIVE ABILITIES"

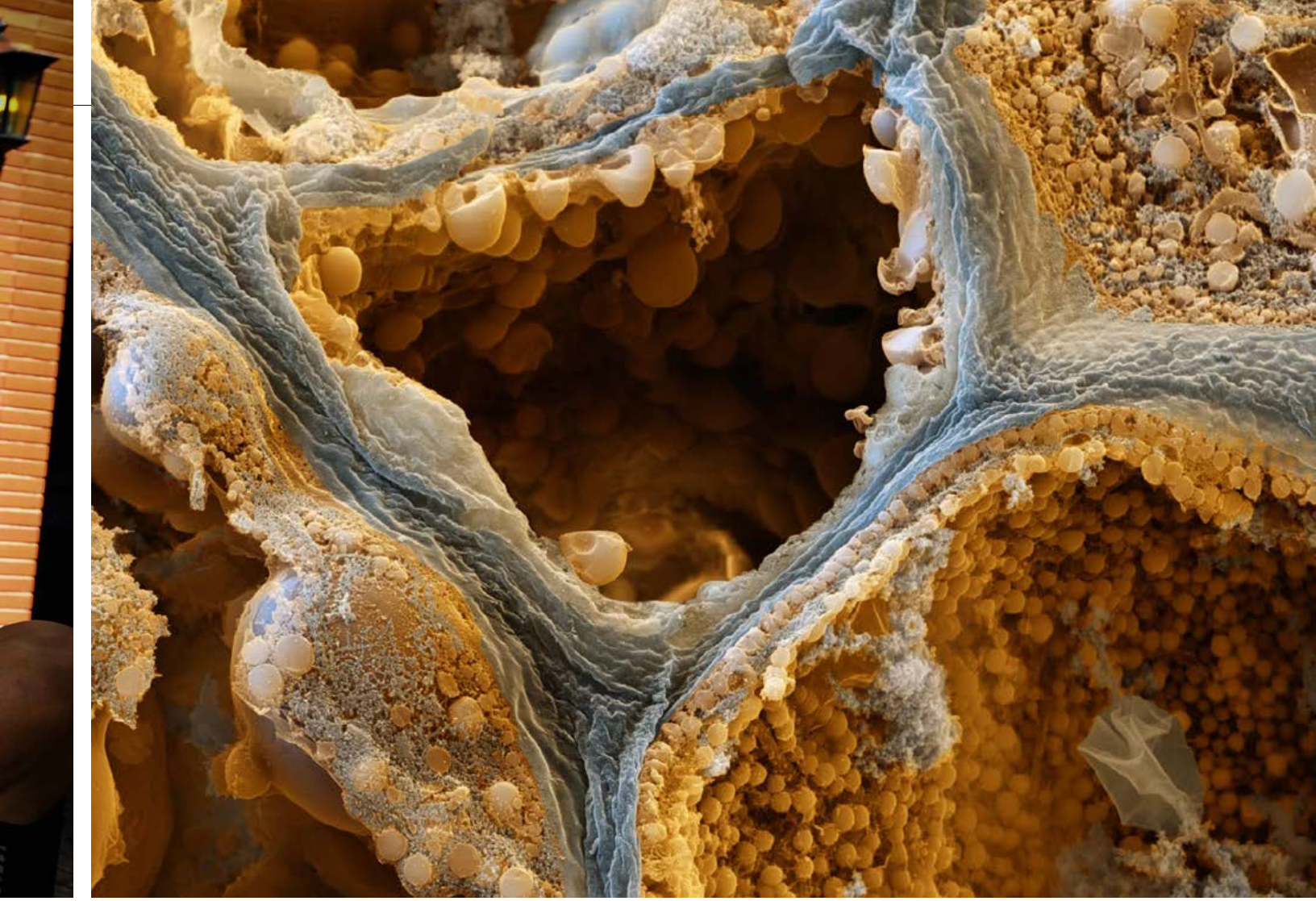
POSITIVE REACTIONS

While the formulations of caffeinated energy drinks, and the effects they have on us has prompted a lot of recent research, there's also a growing interest in caffeine's beneficial effects. For example, caffeine is increasingly being used as a legal performance-enhancing drug in competitive sports. A review of research into caffeine and athletic performance by the International Society of Sports Nutrition in 2022 said caffeine has a 'small to moderate effect' on muscular endurance and strength. Its biggest effects on performance are seen in endurance sports, though. It's thought that at least some of this performance boost is likely down to caffeine aiding muscle contraction by changing levels of calcium, sodium and potassium, as well as acting as a painkiller.

There has also been a raft of studies attempting to determine how caffeine boosts our cognitive abilities. They've found that a moderate dose, up to 300mg, helps us stay focused for longer. Some research also shows that in the long term, caffeine can boost our memory, but here the evidence is somewhat mixed.

When it comes to determining the long-term health benefits of caffeine, things get complicated as most of the research

GETTY IMAGES, SCIENCE PHOTO LIBRARY



has been carried out with coffee, which contains a cocktail of bioactive ingredients. Deciphering whether it's caffeine, or one of the many other components of coffee that brings about a health benefit, is difficult.

There's good news for coffee drinkers, though. A review published in *The New England Journal of Medicine* in 2020 reports that your regular coffee fix reduces the risk of cardiovascular disease, type 2 diabetes, liver disease and certain forms of cancer, such as liver cancer.

For some conditions, such as type 2 diabetes, research shows it's not the caffeine but some other component of coffee that helps to prevent them – as decaf coffee reduces the risk just like caffeinated coffee. "But interestingly, if you look at other conditions, such as Parkinson's disease, it seems to be completely the caffeine," says Rob van Dam, Professor of Exercise, Nutrition Sciences and Epidemiology at The George Washington University in Washington DC, who led the review. "Then there are some that sit in the middle, like liver cancer – it seems that caffeine may have some benefit, but there might be additional gain from some other components of coffee."

In the future, scientists will discover more about how our genes determine the effects caffeine and coffee have on us. And the more we learn, the closer we'll get to the prospect of personalised guidance for daily caffeine intake.

"Most of the guidelines for caffeine have really been just looking at the population level," says Cornelis. "They don't account for the individual variation and we're at a stage in research where there are opportunities for personalised nutrition."

ABOVE The internal structure of a coffee bean, as seen under a scanning electron micrograph

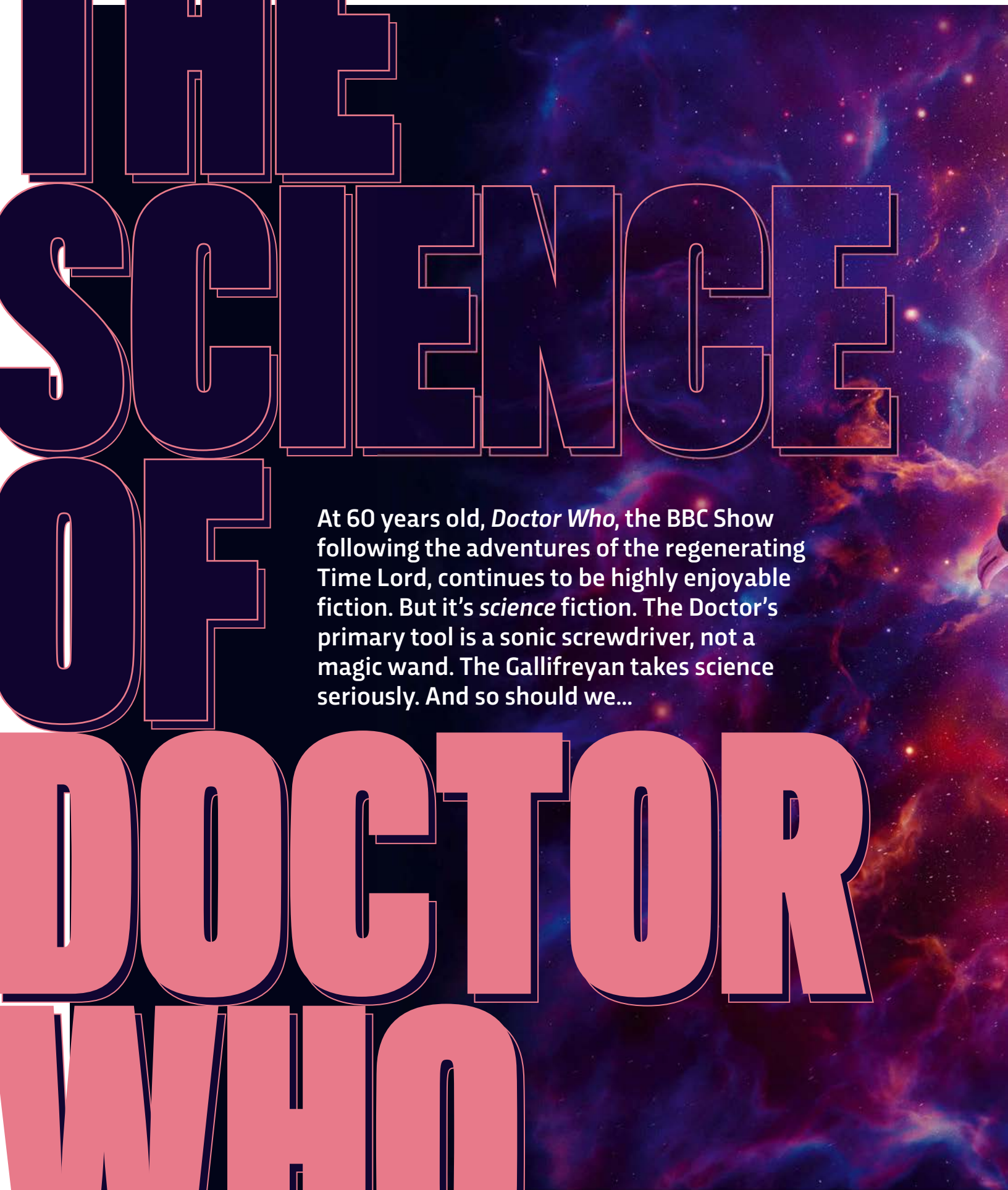
It means that one day a genetic test could tell you precisely what the 'sweet spot' for your daily caffeine intake is. And that day might not be as far off as you think.

"When I first started this genetic research during my PhD around 2001, I couldn't imagine a day where every individual would be able to access their full genome. Well, it's 2023 and we're at that point where people are knowledgeable about their genetics and have paid these companies to get access to them. I've had people email me and say, 'Hey, I just got my genotype back and I read your paper and it looks like I'm a rapid caffeine metaboliser.'" **SF**

by **DR ANDY RIDGWAY**

Andy is a Senior Lecturer in Science Communication at the University of the West of England.

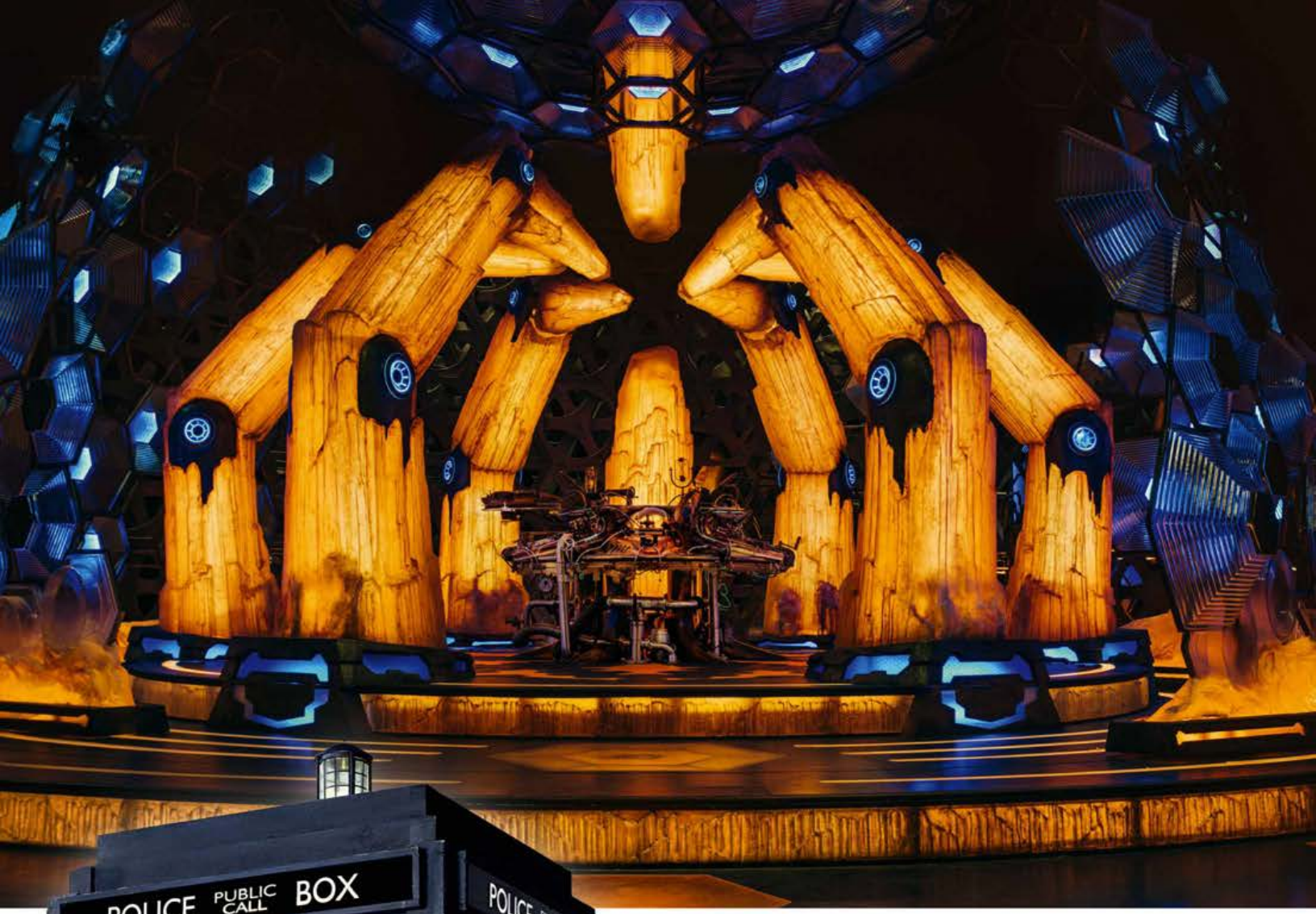
THE SCIENCE OF DOCTOR WHO

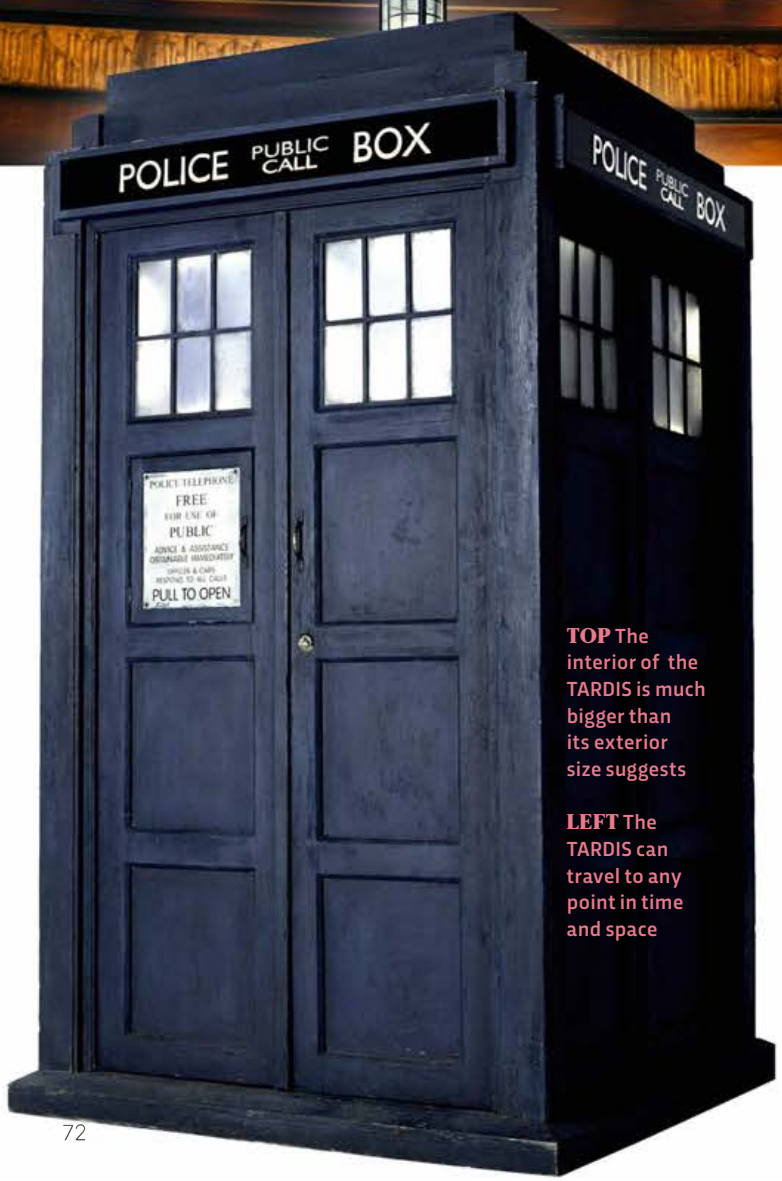


At 60 years old, *Doctor Who*, the BBC Show following the adventures of the regenerating Time Lord, continues to be highly enjoyable fiction. But it's *science* fiction. The Doctor's primary tool is a sonic screwdriver, not a magic wand. The Gallifreyan takes science seriously. And so should we...


POLICE PUBLIC CALL BOX
POLICE PUBLIC CALL BOX
POLICE TELEPHONE
FREE FOR USE OF PUBLIC

BBC STUDIOS





TOP The interior of the TARDIS is much bigger than its exterior size suggests

LEFT The TARDIS can travel to any point in time and space

THE TARDIS

One of the most immediate, and paradoxical, scientific puzzles raised by *Doctor Who* is the nature of the TARDIS, the Doctor's vehicle, home and constant companion.

You know what comes next: 'It's bigger on the inside than the outside!' (Or, as one episode's smart alec put-down line had it, 'It's smaller on the outside!'). With the exterior of an antiquated British police telephone call box – the size of a large-ish wardrobe – it appears to contain at least the volume of a roomy house, if not more. Can this be plausible?

In fact, an imaginative extrapolation of Albert Einstein's theory of relativity might permit the possibility that something being bigger-on-the-inside doesn't have to be immediately ruled out – as well as that old police box's main function, as a time machine. Because relativity is all about distortions of space and time. And as fans of *Doctor Who* know, TARDIS is an acronym of Time And Relative Dimension In Space.

Einstein's great breakthroughs in physics, starting in the early decades of the 20th century, came from imaginative, even playful, dreaming of which the Doctor would probably approve. What, Einstein wondered, would the Universe look like if you

"SPACE AND TIME BEND TO ENSURE THAT OBSERVERS MOVING RELATIVE TO EACH OTHER ALWAYS MEASURE THE SAME SPEED OF LIGHT"

tried to catch up to a beam of light by travelling on a very fast starship? The problem is that the speed of light – around 300,000km per second – is determined by other laws of physics, specifically the laws of electromagnetism. And physics doesn't care how fast you're travelling as you measure that speed; those laws don't change, no matter how fast you go. And so a given beam of light always has the same velocity relative to you – and to everybody else, no matter how they're moving.

So, if Einstein measures the speed of a given beam of light relative to his starship in flight, and a colleague back on Earth measures the speed of that same beam of light relative to their own, apparently stationary laboratory, the two would get precisely the same answer – regardless of how fast Einstein was travelling.

From this apparent paradox, Einstein built his Special Theory of Relativity. Essentially, space and time bend to ensure that observers moving relative to each other, always measure the same speed of light. In particular, as seen from Earth, the accelerating Einstein clock will seem to run slower than those on Earth.

But relativity goes beyond contradictory clocks. Later, Einstein incorporated gravity into his theory (this extended version became known as the General Theory of Relativity) and was able to predict the 'bending' of space-time that maintains the constancy of light speed. This bending was tested in Einstein's day by studying the deflection of starlight by the Sun's gravity, and in recent times by studies of Sagittarius A*, the huge black hole at the centre of the Milky Way.

After more huge conceptual leaps, Einstein's General Theory of Relativity became the essential support for the Big Bang theory, our best model of how the Universe was born and evolves. Not bad for an imaginary ride on a light beam.

All this may seem exotic, but its relevance to the TARDIS is that we all live out our lives in bent space-times. For example, the Sun's mass creates a gravity well with the planets skimming around its 'walls' – their velocity balancing the gravity, not unlike the rolling of the ball in a roulette wheel.

Now, we don't know how Time Lord engineers folded a house into a phone box, but once we know that space-time can be bent and folded and distorted, it takes only a little imagination (or a lot) to put those concepts together.

If you're still unconvinced, consider this. According to the theory behind the Big Bang, the Universe, in its earliest moments, was smaller than a subatomic particle. It could have fitted inside a regular police box – let alone the Doctor's roomy chambers.

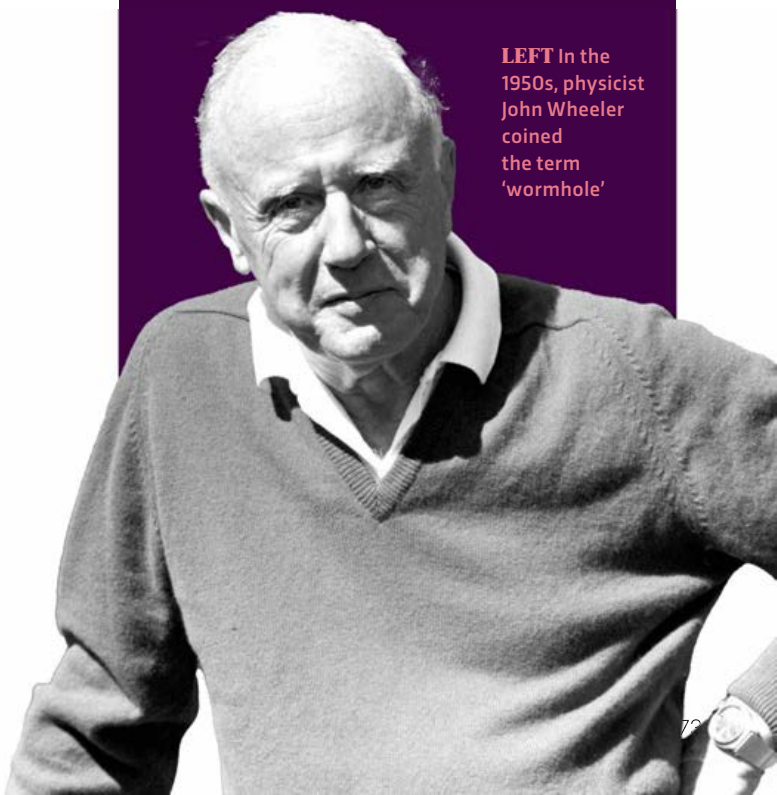
TIME TRAVEL

As for time travel, even with Special Relativity, disturbing time slippages can occur. Consider again the thought experiment of the observers on a spacecraft and Earth. This time, put Einstein on a starship accelerating at one Earth gravity (9.8 metres per second squared).

Einstein, given enough fuel and supplies, could go as far as he liked. And, as we know, to ensure his light-speed measurement is unchanged, his clocks will slow throughout the journey, compared to clocks on Earth.

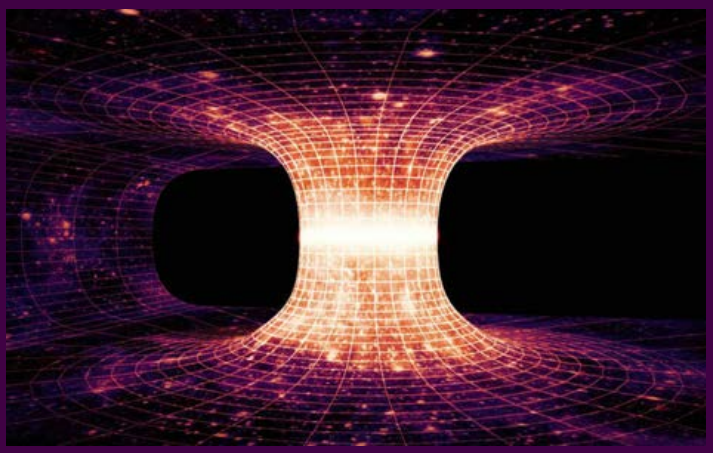
Carry on accelerating at one gravity for 13 subjective years, and Einstein would arrive 1,000 years into the future relative to the observer on Earth (and about 1,000 light-years from home). Suddenly we have a time machine – to the future, at least.

But what about travel to the past? And how could Einstein get home? As it happens, Einstein may also have found the solution to this conundrum in work he started in 1916. He had been studying a relativistic mathematical model of a star – or any spherical, uncharged, massive object – developed by →



LEFT In the 1950s, physicist John Wheeler coined the term 'wormhole'

BBC ARCHIVE X2, ALAMY



ABOVE
Wormholes are theoretical shortcuts through folded space-time and could act like time machines

BELOW
Although hypothetical, it's thought the Milky Way has the potential to contain a wormhole

→ a German mathematician called Karl Schwarzschild. The equations described the gravitational field at a positive distance from the massive object's centre. But Einstein noticed that the equations also worked if you fed in a negative distance. What could this mean, physically?

The physicists eventually realised that space-time could be 'bent' on a large scale, bringing two of these massive objects together to make a 'bridge' that would enable travellers to take shortcuts through space.

By the 1950s, these bridges had been labelled 'wormholes' by American physicist John Wheeler, and the theory behind them has been studied intensely in the years since. Over the same period, wormholes have become a staple of science fiction and what's important for our purposes is that they offer us one way to build a two-way time machine.

"PHYSICISTS REALISED SPACE-TIME COULD BE 'BENT' ON A MASSIVE SCALE"

Recall Einstein's long trip. An observer on Earth, armed with a powerful telescope, would see the ship taking 1,000 years to reach its destination. The time Einstein would measure, with clocks aboard his ship, would be 13 years.

Now suppose Einstein carried one end of a wormhole with him, leaving the other end on Earth. When he reaches his destination, he can simply step through it and emerge back on Earth. Einstein's clock says he's 13 years older; but Earth is 1,000 years older. So Einstein has travelled into his future. Similarly, someone on Earth could pass through the wormhole Einstein appeared from and travel nearly 1,000 years into their past (and emerge aboard a spaceship 1,000 light-years away).

You could imagine a Universe full of wormhole mouths, connecting points across space-time, future and past. A fixed network like this might seem far behind the capabilities of the TARDIS, which can take you anywhere and any when, just as a car gives you a level of freedom the London Underground can't.

Maybe the Time Lords have an altogether more efficient way of doing things. But, as the Doctor might say, what isn't ruled out by the laws of physics is just a question of engineering.

THE SMART TARDIS

Another aspect of TARDIS technology is its controlling AI. We know the TARDIS is super-smart and even capable of empathy, it seems (it certainly has a tight bond with the Doctor). But what kind of technology might support such processing?

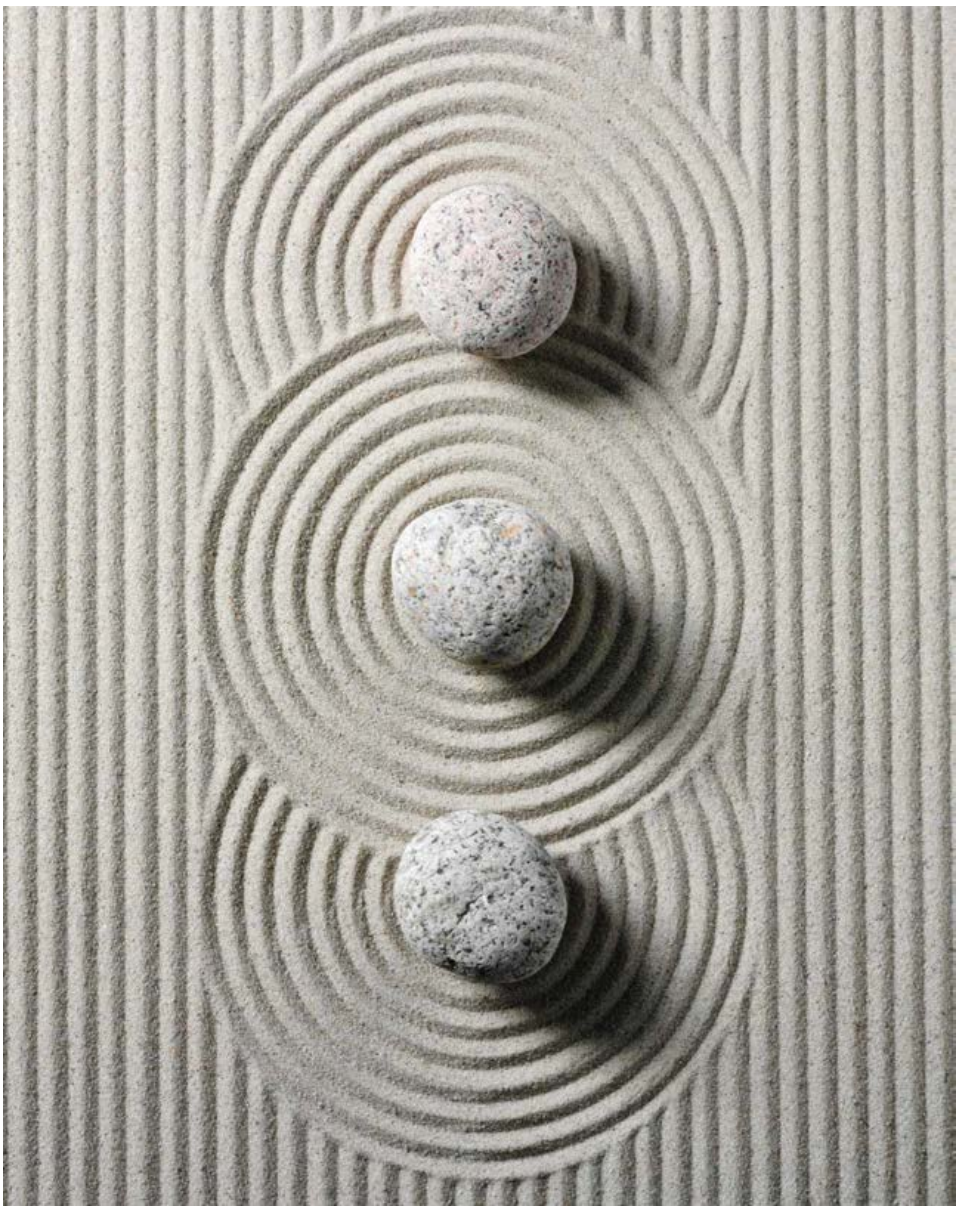
Perhaps the TARDIS, a vehicle navigating highly abstract mathematical spaces, might run on highly abstract mathematical mechanisms. But what kind of mechanisms?

For an up-to-date suggestion, consider the 'three-body problem'. This is a gravitational conundrum that's more than 300 years old, and this year researchers working in Bulgaria discovered more than 12,000 solutions to it.

In Isaac Newton's mathematics, the shared orbit of two bodies is well understood. If one is much larger than the other, as the Sun is larger than Earth, both bodies orbit around a point deep inside the more massive body. If the bodies are of similar sizes, they can both orbit around a shared point in empty space, called a 'barycentre'.

But it becomes more complicated when three bodies are involved. Only about 600 solutions were known until 2017, when about 600 more solutions were found. Now, in 2023, a supercomputer has delivered a whopping 12,392 solutions. And there seems no reason why solutions involving many more bodies can't be found.

These solutions would be magical to watch, as the three bodies loop and dive around each other – and when each 'orbital routine' is finished, it repeats indefinitely. These results have obvious applications for astronomers studying complex stellar and planetary systems. But for our purposes, perhaps these patterns and their more complicated siblings, could also encode a great deal of information in a dynamic, precise mathematical form. Could an array, even a hierarchy, of co-orbiting clusters of n-body solutions store enough data to encode the AI of a TARDIS? Much like the idea of storing data in flocks of starlings in flight… It may be wrong, but I'd bet the true engineering of the TARDIS would be just as beautiful.



GETTY IMAGES X3

"THE TARDIS IS SUPER-SMART AND EVEN CAPABLE OF EMPATHY, IT SEEMS (IT CERTAINLY HAS A TIGHT BOND WITH THE DOCTOR)"

ABOVE The 'three-body problem' is one of the oldest riddles in mathematics and physics

INVASION EARTH

RIGHT As the last surviving Jagaroth, Scaroth made plans to save his species in the 1979 *Doctor Who* serial 'City of Death'

BELOW Cybermen come in many forms, but first appeared in the Who Universe living on Mondas, Earth's twin on the edge of the Solar System

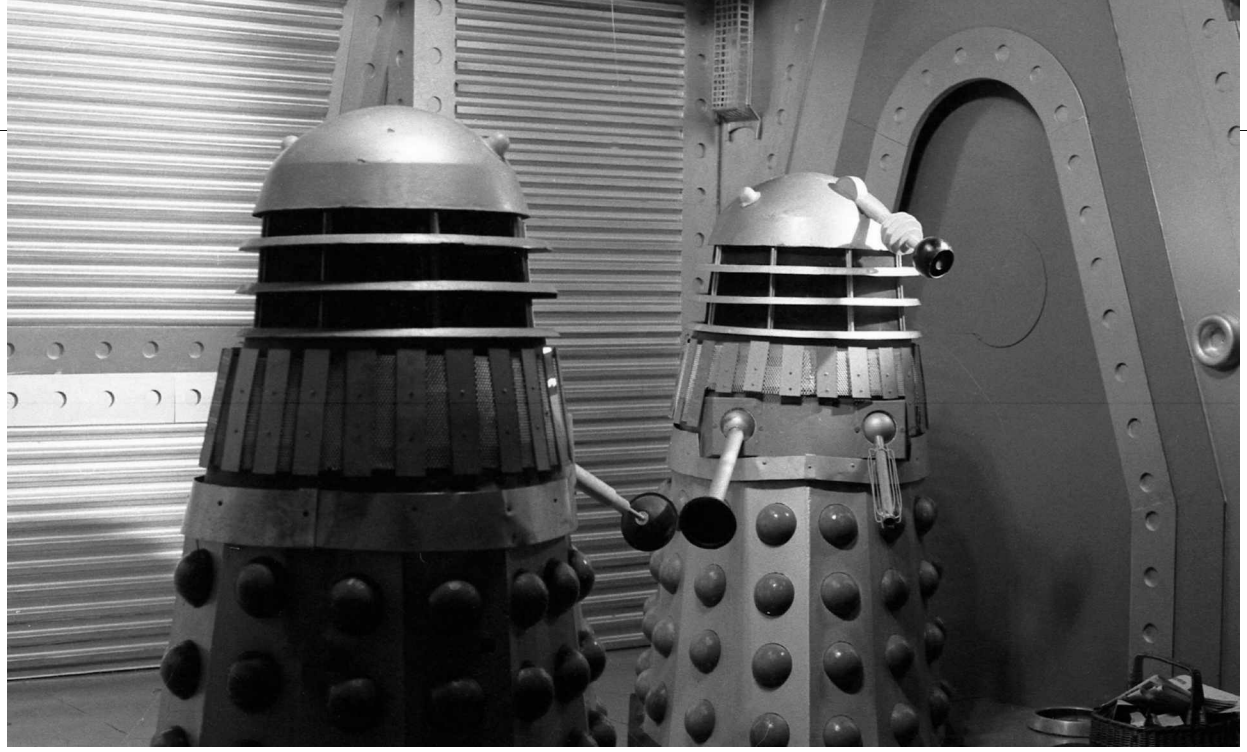
The Earth of *Doctor Who* has suffered multiple alien invasions.

The earliest (in the show's history), as depicted in the serial 'City of Death' in 1979, was by a warrior race called the Jagaroth 400,000,000 years ago. A survivor called Scaroth left fragments that deflected the history of Earth and humanity from then on. So, in the Who universe, an engagement with the alien has been woven into our evolution.

A clumsier, but just as devastating, intervention occurred 65 million years ago when, according to the serial 'Earthshock' in 1982, a massive interstellar freighter travelled back in time and crashed to Earth – an impact that wiped out the dinosaurs, as opposed to a rogue asteroid strike as scientists would have it. We can even guess at the dimensions of the freighter given a (real-world) study of the dinosaur event.

The asteroid, which hit with the energy of 4.5 billion Hiroshima bombs, must have been roughly the size and mass of Mount Everest. But a mass of a 1,000 tonnes of antimatter would deliver the same bang – a mass that could propel a 1,000-tonne freighter to Alpha Centauri at close to the speed of light.

We may have seen an alien vessel, or the wreckage of one, wandering through our Solar System in recent years – the anomalous 'Oumuamua object. Its high velocity proved it came from outside the Solar System and its long, thin shape was highly unusual. Probably it was nothing more than an exotic asteroid fragment, but if it had struck Earth… well, it was no 'Earthshock' freighter. At an estimated mass of 40 tonnes and travelling at 40 metres per second, 'Oumuamua would have burned up in Earth's atmosphere.



LEFT Daleks were found on the planet Vulcan, within the orbit of Mercury, in the 1966 *Doctor Who* story 'The Power of the Daleks'

BBC ARCHIVE X3

ROGUE PLANETS

Doctor Who is entertainment, but it has scored some predictive hits concerning the advance of scientific knowledge over the decades. For example, it has long been a peculiarity of the show to feature rogue planets in our Solar System.

When the show first aired in 1963, it was believed that there were nine planets in the Solar System, with the furthest out, Pluto, discovered only a few decades before. And it was believed that these planets had emerged from a reasonably logical and orderly formation process. You had the rocky worlds closest to the Sun: Mercury, Venus, Earth and Mars. Further out, where temperatures were lower and the planets could retain huge volumes of gases and ices, you had the gas giants (Jupiter and Saturn) and the ice giants (Uranus and Neptune), with Pluto at the edge of the system.

So scientific eyebrows would have been raised by 'The Tenth Planet', the first Cyberman story, broadcast in 1966 and set in 1986. This featured Mondas, a rogue planet on the edge of the known Solar System. This, and the Cybermen, were a threat to Earth, but eventually the planet apparently left the system under its own power.

Then came Vulcan, in 'The Power of the Daleks', also broadcast in 1966: a planet inside the orbit of Mercury, which also disappeared, in this case in the show's year 2020. (Early astronomers had hypothesised the existence of a Vulcan, but this turned out to be caused by misread sightings of Mercury.)

And then there was Voga in 'Revenge of the Cybermen', broadcast in 1975 – a world made entirely of gold. This planet had wandered into the Solar System and become a satellite of Jupiter. By the year 2875 it had become a target for human miners.

Such exotic and wandering planets didn't fit into the orderly Solar System models that were current in 1963, and perhaps added to the show's sense of implausible fun. But time, deeper observations and more mature theoretical modelling have changed our view of the origin of the planets. And now we know that the Solar System itself has a more complex history than once believed.

Just three years after 'The Tenth Planet' was broadcast, for example, with attention focused on the Moon due to the Apollo missions, the Big Splash theory of the Moon's origin was developed. During the formation of Earth, another protoplanet with the mass of Mars (called Theia) crashed into Earth, causing huge ejections of rock that eventually coalesced into the Moon.

Later, in 1992 (14 years before our perceived outermost planet was controversially downgraded to dwarf planet status), came the discovery that Pluto isn't the limit of the Solar System. Beyond it – between 30-40 times Earth's distance from the Sun – lies the Kuiper belt, a swarm of objects made of rock and ices, with over 100,000 so far detected that are over 100km (60 miles) in diameter. Among that swarm are five 'dwarf planets' on looping orbits: Orcus, Haumea, Salacia, Quaoar, and Makemake. And our view of the formation of the Solar System has continued to evolve.

Doctor Who may push its luck in terms of plausibility sometimes, but at least it sticks to something like science in spirit. And, as in its prophesy of wandering worlds, sometimes it gets it more right than wrong. **SF**

by **STEPHEN BAXTER**

Stephen is a hard science-fiction author. His latest book is Creation Node *(Gollancz £25). Find out more at stephen-baxter.com.*

Q&A

Email your questions to **questions@sciencefocus.com** or submit on X (formerly Twitter) at **@sciencefocus**

YOUR QUESTIONS ANSWERED

FAYE CHASE, VIA EMAIL

WHY IS SOCIALISING SO TIRING?

There's a lot that goes into a social event. You might be flexing your muscles on the dancefloor or using them to sit still at a fancy dinner table. There's likely a lot of sensory stimulation that you might be taking in to dance to the beat, or trying to block out to concentrate on what's being said. Running through your mind could be all the things you want to remember about the event, or your anxieties, or goals for the interaction.

All this activity is understandably taxing on your mind and body. But you've probably heard it said that extroverts gain energy from being around other people, while introverts get their energy from being alone. Does this mean that extroverts don't get tired of socialising?

We all fall somewhere on a scale between introversion and extroversion – nobody's solely one or the other. Extroversion is considered one of the 'Big Five' personality traits and, while there is a genetic component to your experience of extroversion and introversion, the impact of your personality preference on your in-the-moment behaviour varies depending on the situation. Sometimes you're outgoing and talkative, exhibiting a more extroverted personality, and other times you're more reflective and reserved, or introverted.

In studies that have tested levels of extroversion, results indicate that there's a connection between a more introverted personality and fatigue. It's not simply the case that extroverts never tire of social interaction, though. *Everyone* will feel exhausted after a lot of socialising; it's just that the upper limit will vary from person to person.

Research into the fatiguing effects of social interactions has identified some common factors among those considered most tiring. Conversations that were long, difficult or intense, felt more tiring. If a person was trying hard to make a good impression or meeting lots of new people, they were more likely to feel drained afterward. Conflict and complaint also took more energy.

DR HELEN PILCHER
Biology

PETE LAWRENCE
Astronomy

AMY ARTHUR
Lifestyle and wellness

DR CHRISTIAN JARRETT
Psychology

CERI PERKINS
Environment

LUIS VILLAZON
Engineering and technology

PROF PETER BENTLEY
Technology

DR ALASTAIR GUNN
Astrophysics

This means that it may be possible to reduce the tiring effect of socialising by actively seeking encounters that make you feel at ease, that don't involve too many new people or that allow for breaks during long conversations.

To recover from social exhaustion, many people choose to be alone. This can help if the most tiring part of socialising is the interaction itself. But if social anxiety or depression is what makes mixing with others exhausting, solitude can potentially exacerbate the problem.

It's thought that the emotions you experience during social events can also have an effect on your feelings of fatigue. If you have to spend a long time suppressing your true feelings, or showing a certain emotion that's at odds with what you really feel, you could be more prone to emotional exhaustion and burnout.

"IT'S THOUGHT THAT THE EMOTIONS YOU EXPERIENCE DURING SOCIAL EVENTS CAN ALSO HAVE AN EFFECT ON YOUR FEELINGS OF FATIGUE"

For example, 'service with a smile' jobs could make servers more tired, and care workers who are unable to show their grief or fear for their patients may find themselves emotionally drained outside of work. To combat this, it's suggested that you make time to express your feelings and accept and acknowledge that they're valid, reducing the emotional dissonance wherever possible. ***AA***

ALAMY, GETTY IMAGES ILLUSTRATION: PANAGIS MATSANGOURAS

RODNEY MINNS, HAMPSHIRE

HOW DOES THE BBC KNOW HOW MANY PEOPLE ARE WATCHING *DOCTOR WHO*?

They go online and visit barb.co.uk – you can too. Barb (the Broadcasters Audience Research Board) is owned by the major UK TV channels and the Institute of Practitioners in Advertising. It uses a special panel of 7,000 households in the UK, selected based on geography, demographics and TV platforms, which represent the entire UK population. Viewers in each household have special remote controls with unique buttons for each person, to help record exactly what programmes were being watched and when.

This data is added to data from the household's Wi-Fi router to understand what video subscription or on-demand service was being used, and data from connected devices to track viewings of a broadcaster's video on demand. ***PB***

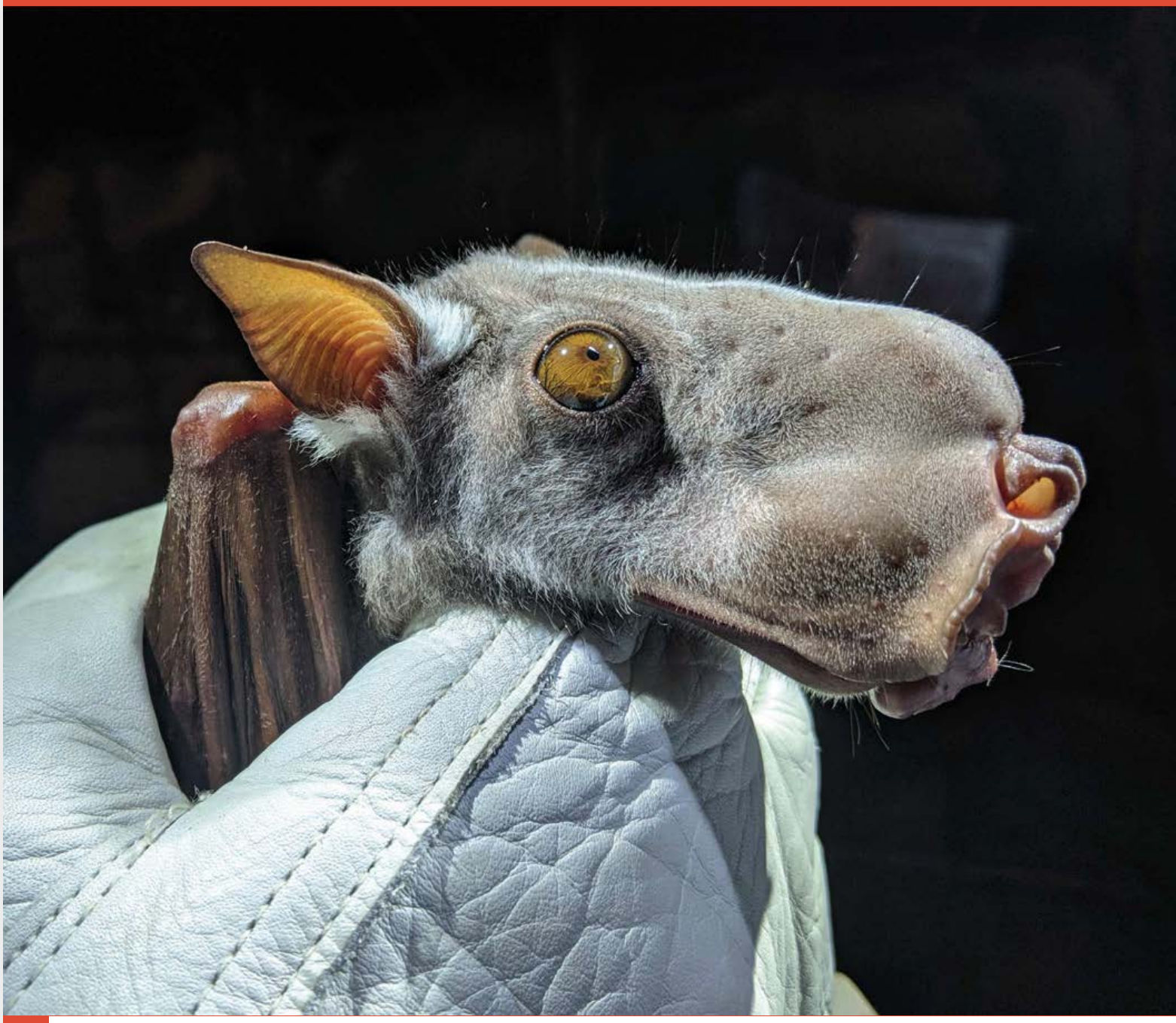
MARK ONEAL, BRIGHTON

HOW DO PEANUTS GROW?

Peanut plants are unusual because they flower above ground, but fruit below it. That's why peanuts, which are native to South America, are often referred to as 'ground nuts'. About 40 days after planting, delicate yellow blossoms appear around the lower third of the plant. After a few days, these self-pollinating blooms crumple and die, revealing budding ovaries known as 'pegs'.

Here's where things get weird. As their petals shrivel, the pegs' stems curve downward, plunging the pegs into the soil. Underground, they slowly develop into pods, each containing a pair of seeds – or peanuts. The whole process, from planting to harvest-ready, takes about five months. ***CP***

NATURE'S WEIRDEST CREATURES



HAMMERHEAD BAT

With a face that wouldn't look out of place among the Notre Dame gargoyles, the hammerhead bat is what the French would call '*jolie laide*'. The phrase, which literally translates as 'pretty ugly', refers to a beauty that defies conventional standards. With the ears of Yoda, the face of the racehorse Desert Orchid and nostrils that resemble some kind of sea creature, the hammerhead bat's face is one messed-up mash-up. Until you realise that this oddly proportioned animal is an evolutionary triumph.

It lives in the lowland rainforests of West and Central Africa, where it feasts on fruit and flies at night. It is unusual because it's the only bat species known to operate a lek mating system, a kind of competition where males show off to impress the females, a bit like *The X Factor*.

Twice a year, during the dry seasons, up to 150 males come together and hang from riverside trees. Then they flap their foot-long wings and honk. It's a strange, low-frequency noise that begins slowly and then speeds up to a rapid, staccato buzz, with up to 120 'beats' per minute. Lovelorn males 'sing' for hours at a time, as the females fly by and judge the competition. The males with the sexiest

songs are the one that gets to mate. Again, a bit like *The X Factor*.

The females are very choosy, with just six per cent of males involved in 79 per cent of matings. It's important, then, for a male to belt out a top tune, and they have evolved a number of highly specialised adaptations to do so.

The larynx, which is used to produce that hammerhead honky-tonk, is nearly three times larger in males than in females and takes up around half of the male's body cavity. Large resonating chambers set inside a long, boxy head help to amplify the honks, while flayed nostril-like structures and fluted lips help to project the song further.

Females don't have to sing for sex so they have no need for the same sort of complicated headgear. As a result, they have evolved to look very different, with smaller bodies and compact, fox-like faces. Indeed, hammerhead bats are thought to be the most sexually dimorphic bat species in the world.

As with all true lek species, females take sole responsibility for caring for the young. After a six-month pregnancy, they give birth to a single offspring, or sometimes twins. Females become sexually mature at six months old, while males take a further 12 months. Individuals display a mixture of solitary and social behaviour, but best of all, when they sleep, they wrap their wings around their noses.

The hammerhead bat is, happily, listed as of 'least concern' by the International Union for the Conservation of Nature, which means it's unlikely to become endangered or extinct in the near future.

Life's not all rosy though. They're sometimes killed by farmers when they steal crops, and in Nigeria and the Democratic Republic of Congo, the bats are consumed as bushmeat. ***HP***

GETTY IMAGES, DR SARAH OLSON X2

JENSEN PITTS, VIA EMAIL

CAN I REALLY MAKE A DIFFERENCE BY RECYCLING?

Recycling is not a silver bullet that will halt climate breakdown. Not even close. Its potential impact – a saving of around 11 gigatonnes of carbon dioxide (CO_2) over 30 years if the whole world recycles more than 80 per cent of its municipal waste – is dwarfed by the amount of greenhouse gases currently released by fossil fuels and industry: 36.8 gigatonnes in 2022 alone.

Today, recycling in the UK saves an estimated 18 million tonnes of CO_2 emissions each year – the equivalent of pulling 5 million cars off the road. That may sound promising, but it's only a 2,000th of the CO_2 emissions currently generated each year by fossil fuels and industry, and roughly a 200th of that generated by agriculture or the global fashion industry.

These numbers are disheartening. So what's a well-meaning person to do?

REDUCE, REUSE, RECYCLE

First, don't give up on recycling; it's easy to do and it helps reduce landfill and slow the rate at which we extract Earth's resources.

As for how much difference one person can make, if you take the 18 million tonnes figure above and divide it by the UK's 67 million inhabitants, it suggests that the average Brit currently saves around 269kg of CO_2 a year by recycling. According to the Department for Environment, Food and Rural Affairs (DEFRA), Brits recycled 44 per cent of their household waste in 2021. The figures suggests that a typical Brit could bump their CO_2 savings up to 610kg a year by recycling 100 per cent of their waste.

If you really want to move the needle, though, pay attention to your choices earlier in the consumption pipeline. For instance, opt for loose fruit and veg; pick solid cleaning products (dish soap, laundry detergent strips) over liquids in plastic bottles; mend or repurpose old clothing; and the big one: buy less stuff. Switch your emphasis to the Reduce and Reuse parts of the 3R mantra, and keep Recycle for when you've exhausted the other options.

START WITH ONE THING

If it all feels overwhelming, try picking one thing and building from there. For instance, if you grab a lunchtime meal deal each work day, you could easily rack up 250 plastic bottles over a year. Estimates vary, but by switching to a reusable bottle you could save 20kg of CO_2 each year.

Meanwhile, a review of over 7,000 studies from across the globe listed the most effective changes to household consumption. They include taking one fewer long-haul flight per year, choosing public transport and making your home more energy efficient.

So recycling alone won't fix the climate crisis, but it nudges things in the right direction. And we're not powerless as individuals to effect change. ***CP***

ADRIANNA GARDNER, CHELMSFORD

WHAT IS THE DEADLIEST CREATURE IN THE UK?

Mosquitoes are infamously the world's most deadly animal, killing up to a million people every year via the diseases they spread, such as malaria and dengue fever. In the UK, however, our 36 native mosquito species pose little in the way of threat, so they don't feature in the three-way tie for the title of UK's deadliest creature.

One of the three that does, is dogs. Rishi Sunak, the prime minister, recently added American XL bully dogs to the list of banned breeds after a rise in dog-related deaths. Numbers were around three per year, but in 2022, 10 people in England and Wales died from dog bite injuries, the tragic result of irresponsible ownership and a trend for breeding bigger, more muscular dogs.

Small can be deadly too, though. Hence bees and wasps also have a claim to the title. For the 0.5 per cent of the population who are allergic to the venom in their stings, the resulting anaphylaxis can be fatal. It causes the death of between two and nine people in the UK every year.

The final culprit is less obvious. Picture a pastoral scene and it's hard to imagine that the cattle grazing so peacefully could be deadly, yet cows attack up to 4,000 people in the UK every year. And around five of those people die from their injuries. Most deaths are among the farming community, but walkers can be at risk too. In the wild, cattle are a prey species, so new mothers are primed to defend their calves. Most accidents occur when natural boundaries are ignored. Cattle can injure people by knocking them down and trampling or lying on them. The best advice is to keep dogs on leads and give herds of cattle a respectfully wide berth. ***HP***

FABIAN MCNEIL, VIA EMAIL

HOW DO IQ TESTS WORK?

In 1904, English psychologist Charles Spearman discovered there was a strange link between certain mental skills, such as mathematics, verbal fluency, spatial visualisation and memory. He found that people who did well at one tended to do well at others, while those who did poorly at one would do poorly at others. And his finding has been shown to be true so many times that it has been called "arguably the most replicated result in all psychology".

By using statistics, it's possible to derive a single factor, known as general intelligence (g), that indicates the level of general cognitive ability compared to other people. This general intelligence has been divided into two types. The first is fluid intelligence (gf), which doesn't depend on formal education and is more about solving abstract reasoning problems. The second, crystallised intelligence (gc), is more about learned experience, general information and vocabulary. Researchers claim that gf peaks at around age 20 and then declines, while gc stays stable or improves with age. It's known that g is heritable – you're likely to inherit mental skills from your parents.

We can estimate general intelligence (g) using intelligence quotient (IQ) tests. These are standardised tests that provide highly reliable results. This means that even if a

person does several different IQ tests, they're likely to achieve much the same score each time.

There are many kinds of IQ tests, focusing on different cognitive abilities, but all rely on the fact that if you score well in one kind of mental task you're likely to score well in others. The raw IQ score is adjusted using statistics to ensure that about 66 per cent of people will score between 85 and 115, and 2.5 per cent will score more than 130 or less than 70. Raw scores have been rising over the decades, however. One study showed that British children's raw IQ scores rose 14 points from 1942 to 2008.

IQ tests have shown to be predictive of job performance, income, social status, nutrition and even mortality. But despite their reliability, they've had a torrid history. Some of the originators became involved in eugenics, believing high IQ could be bred into populations. It still has fierce critics. IQ is measuring one aspect of our brains, but there are other kinds of intelligence, such as emotional intelligence or rational thought, where you're able to make good judgements and decisions.

Some liken IQ to measuring the brightness of a searchlight – it may be bright, but pointed in a silly direction it illuminates nothing of value. Many people with high IQs are successful, but not everyone with high IQs will be sensible, rational or make good choices in life. ***PB***

ALAMY X2 ILLUSTRATIONS: PANAGIS MATSANGOURAS, PETE LAWRENCE

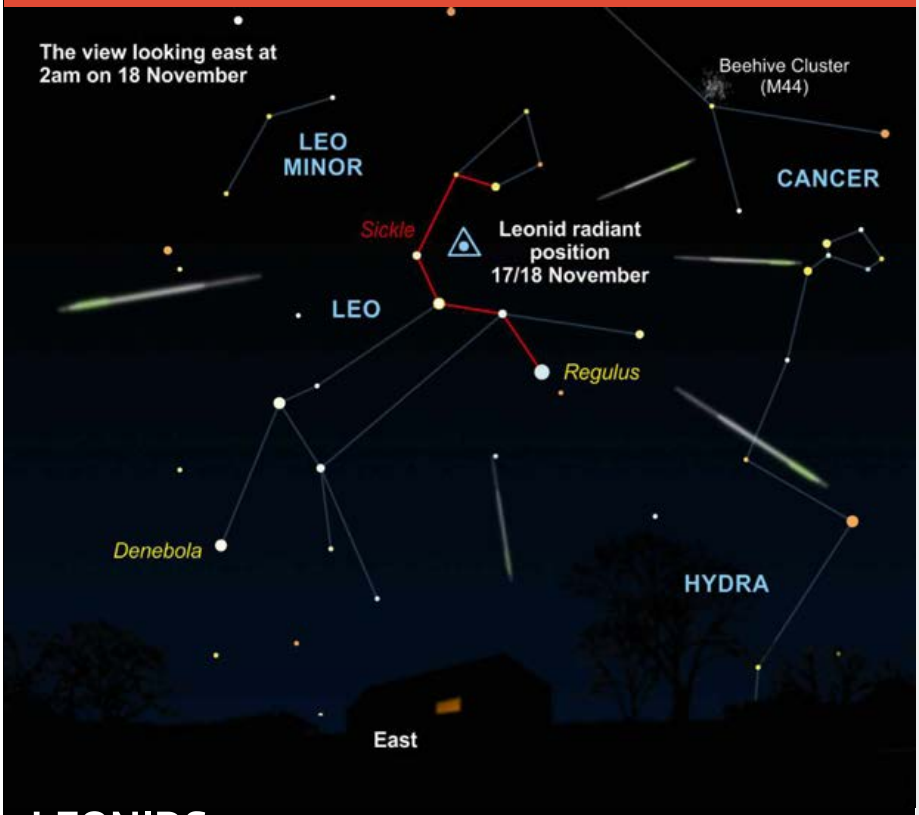
ALICE SKINNER, NOTTINGHAM

IF YOU FARTED HARD ENOUGH IN SPACE, COULD YOU MOVE YOURSELF AROUND?

A 1991 study at the Royal Hallamshire Hospital in Sheffield found that volunteers produced an average of 705ml of farts per day on a diet that had been supplemented with baked beans.

This sounds like a lot, but even for the fartiest person, it only amounts to around half a gram per day. You would have to eject this at 200km/s to move yourself at walking speed – that's 26 times faster than the International Space Station orbits (7.6km/s). And this ignores the damping effects of clothing. In an 'ask me anything' in 2013, former ISS commander Chris Hadfield said, "We all tried it. Too muffled, not the right type of propulsive nozzle." ***LV***

ASTRONOMY FOR BEGINNERS



LEONIDS

WHEN: MID TO LATE-NOVEMBER

The Leonid meteor shower is active between 3 November and 2 December. Peak rates occur mid-November, with this year's peak predicted for 6am UST on 18 November. The shower is named because its radiant (the area of sky from which the meteor trails appear to originate) is within Leo the Lion. The radiant is within the Sickle, a backward question mark pattern (called an asterism) of stars. The night of 17/18 November should give the best rates, but if the weather is poor, the nights before and after should be fine.

Leonid meteors are associated with comet 55P/Temple-Tuttle, Earth's passage through this comet's orbital debris typically bringing a peak zenithal hourly rate (ZHR) of 15-20 meteors an hour. That assumes perfect viewing conditions that are rarely met, so expect the true visual hourly rate to be lower.

The Leonid shower is famous because of outburst events occurring at roughly 33-year intervals. During such periods peak rates may increase significantly, sometimes producing thousands of meteors per hour. The next predicted outbursts are for 2033 and 2034, when ZHRs are predicted to be 400 and 500 respectively.

On 17 November, the Moon sets around 5pm UST, leaving the sky good and dark. The radiant doesn't rise until 10:30pm UST, so watch from 11pm UST until dawn on 18 November. Leonids are among the swiftest meteors, the particles forming Leonid trails entering our atmosphere at a speed of 70km/s.

A reclining garden chair makes a perfect viewing platform on a clear night. Adjust it so you're looking two-thirds up the sky, preferably towards the south. Allow at least 20 minutes in total darkness before starting a watch to give your eyes time to properly adjust to the dark. ***PL***

by **PETE LAWRENCE** (*@Avertedvision*)
Pete is an astronomy expert and presenter on The Sky at Night.

Seasons of Sleep

How taking a nap can be the ultimate survival tool

Infographic by James Round

SOURCES Wikipedia, US National Park Service, The Woodland Trust, *Discover Magazine*, *Scientific American*, European Space Agency, Bumblebee Conservation trust, Australian Academy of Science, *The Independent* and the North American Bear Centre.

An overarching rule of the natural world is the old adage 'survival of the fittest'. Only those best adapted to their environments stand a chance of enjoying any kind of longevity. These adaptations come in many forms, be it camouflage to blend in more effectively, longer legs to run faster or sharper teeth to hunt better. Evolution provides the means for a species to improve itself over time, so that genetic quirks can become essential traits for survival.

One of the most intriguing evolutionary adaptations is hibernation, which provides an extreme, but effective way to avoid challenging situations. With tough times ahead, an animal can drift into a state of minimal activity until things improve. It's a process seen across the natural world in many forms and an incredible number of species. But what happens during hibernation? How does an animal prepare? And could humans ever benefit from nature's long nap?

Why do animals hibernate?

The objective of hibernation is to save energy during challenging situations. It's triggered by two ecological imperatives...

Environmental stress

Animals require a stable internal temperature, which can be difficult to maintain in extreme weather.

Food scarcity

Changing temperatures can also severely limit the availability of essential food.

The stages of hibernation

One of the natural world's most famous hibernators is the bear. Most bears hibernate, but the exact timings and approaches can differ based on the species, environmental factors and other considerations such as pregnancy. For all bears that hibernate, it's an essential act of survival and defines a large part of their year. Here's a more detailed look at the role of hibernation in the life of an American black bear. These impressive mammals live in forests throughout the United States and hibernate over winter for between three and eight months.

1

Normal activity

Between spring and autumn, bears will usually eat between 5,000 and 8,000 calories a day, with 85 per cent of their food coming from vegetation. Normal respiration for a bear is between 6 and 10 breaths a minute, with a heart rate of 40 to 50 beats per minute.

2

Hyperphagia

During this period of excessive eating and drinking, bears can eat up to 20,000 calories a day as they fatten themselves up in preparation for hibernation. They also drink several gallons of water a day to process the copious amounts of food and rid their bodies of waste.

A world of hibernation

When you think of hibernation, your first thoughts may be of a small mammal settling down for a winter rest. But hibernation comes in lots of different forms. Most species hibernate in the winter, but some do so during hot weather in a process called aestivation. Some species hibernate spontaneously, responding to built-in triggers, while others do so in response to external environmental stressors. And, while the most common hibernators are small mammals, it's a process that's seen across the animal kingdom.

Little brown bat

To survive winter, some bats migrate while others hibernate. The North American little brown bat does the latter, hibernating in large colonies for around six months within caves or rock crevices. During this time bodily functions slow significantly, reducing the bats energy usage by 98 per cent.

Arctic ground squirrel

This squirrel goes to ground for around seven months over winter, slowing its heart rate to just one beat per minute. Its body temperature can drop as low as -3°C. It's thought that its blood doesn't freeze because it can cleanse its body of the particles necessary for ice crystals to form.

Fat-tailed dwarf lemur

This Madagascan native is the only hibernating primate. It does so in the summer dry season for up to seven months to avoid food scarcity. They fatten up beforehand, storing the fat in their tails, which can reach up to 40 per cent of their body weight.

What happens to an animal during hibernation?

No two species hibernate in exactly the same way. Generally though, when an animal enters a state of hibernation, most of their bodily functions will either completely stop (urination, for example) or slow down significantly (such as heart rate).

Temperature drops

An internal temperature closer to that outside means less energy is required for thermoregulation.

Metabolism slows

Species mostly don't eat or drink, and instead live off fat deposits or food caches.

Heart rate slows

Breathing becomes infrequent and shallow. Some species (wood frogs) stop breathing completely!

Lack of awareness

During hibernation, some species become dangerously oblivious to their surroundings.

Could humans hibernate?

We don't hibernate and neither did our recent ancestors; over the last few hundred thousand years, we've always lived in a fairly temperate climate with good food availability. But could we? Scientists now believe we may still have the biological mechanisms of more distant ancestors that would make it possible to enter a state of hibernation in the right circumstances. This is an enticing idea, because hibernation is often discussed as a key enabler for the future of human space exploration, to help astronauts endure long and arduous journeys through deep space.

3

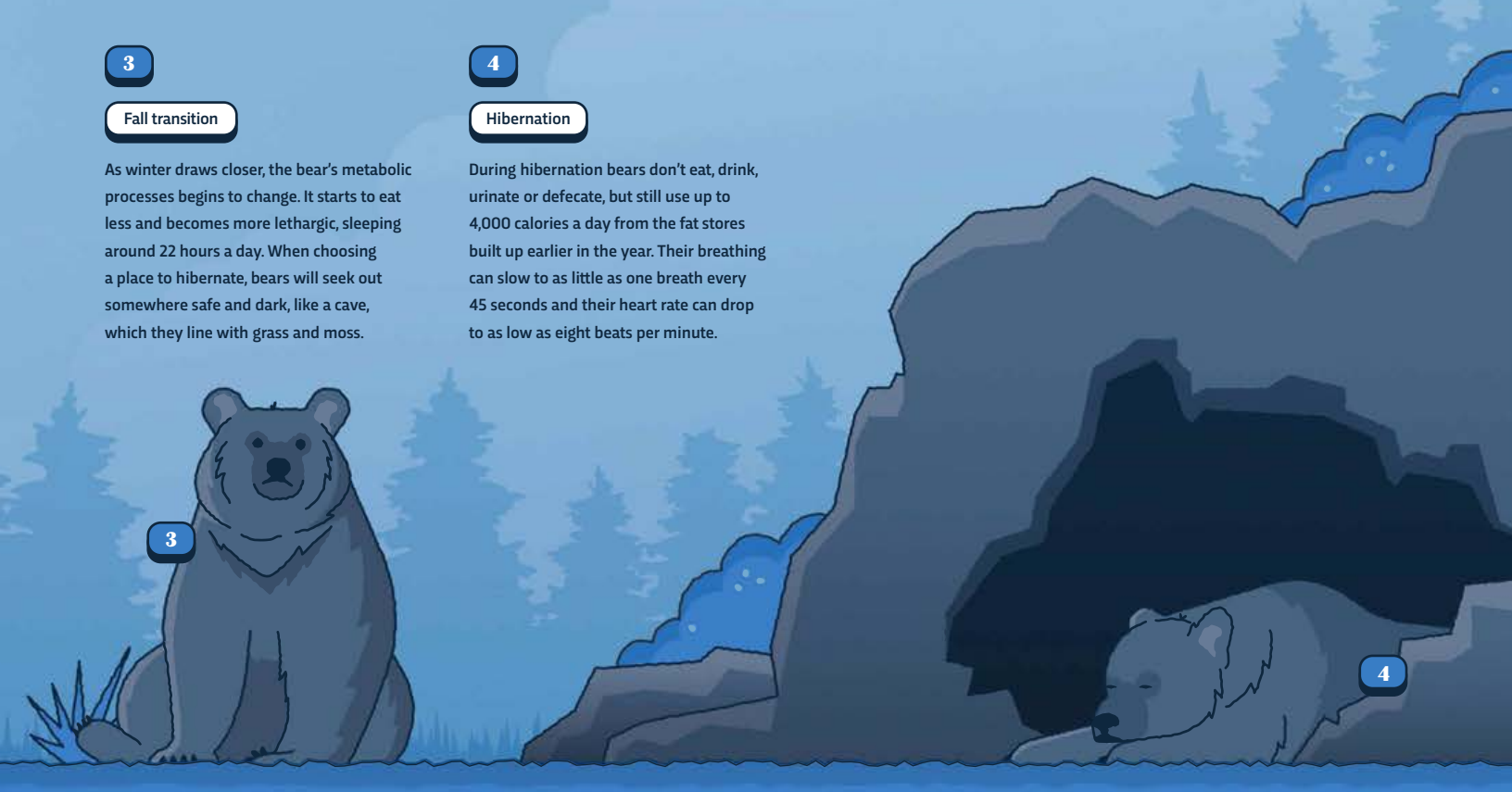
Fall transition

As winter draws closer, the bear's metabolic processes begins to change. It starts to eat less and becomes more lethargic, sleeping around 22 hours a day. When choosing a place to hibernate, bears will seek out somewhere safe and dark, like a cave, which they line with grass and moss.

4

Hibernation

During hibernation bears don't eat, drink, urinate or defecate, but still use up to 4,000 calories a day from the fat stores built up earlier in the year. Their breathing can slow to as little as one breath every 45 seconds and their heart rate can drop to as low as eight beats per minute.



Common poorwill

While many birds migrate to escape colder weather, the common poorwill does something more unique – it's the only bird known to hibernate. To conserve energy and heat during winter, this bird slows its heart rate and breathing, and lowers its body temperature for weeks or even months.

Bumblebee

Not all bumblebees hibernate – only the queens. When the colony dies at the end of summer, new queen bees hide themselves underground away from predators and the risk of starvation and disease. When spring arrives they emerge, ready to find a nest site and begin a new colony.

Garter snake

As cold-blooded animals, it can be a struggle for reptiles to survive in cold environments. Many practise a form of hibernation called brumation. Some species, like the garter snake, hibernate communally in large groups that can number in the thousands.

Wood frog

Most frogs hibernate, but wood frogs do something even more remarkable: they freeze! For up to eight months a year, they exist in a state of suspended animation, with no heartbeat and a body filled with ice. And once spring comes around again, they awaken, completely undamaged.

DEAR DOCTOR

IS IT REALLY BETTER TO HOPE FOR THE BEST, BUT BRACE FOR THE WORST?

Say you're waiting for school exam results, or you have a dental appointment coming up. A lot of people believe that they can prepare themselves for these sorts of uncertain outcomes by assuming the worst will happen. That way, if you get poor exam results or the dentist trip turns into a drilling ordeal, it won't come as such as shock. Hence the expression, 'hope for the best, plan for the worst'. But is this strategy really beneficial?

Based on psychology research findings, the short answer is no. The first drawback is that bracing for the worst will make you feel sad and anxious before the event. This makes sense. After all, you've convinced yourself something bad is going to happen. For obvious reasons, you'll feel better in the lead up to the exam results, the dental visit (or whatever uncertain and daunting event you have coming up) if you think positively and assume it'll go well.

But what about if you end up bombing the exam or the dentist gets trigger happy? Won't bracing yourself take the edge off these negative experiences? Isn't it possible to erect a kind of emotional shield? Unfortunately not. We don't have data for every conceivable situation, but at least in the context of exam results, there's ample evidence that people who receive disappointing grades feel just as bad whether they expected them or not – and that's true both right after getting the results and in the days afterwards. Another similar study showed that having negative expectations about an upcoming public speaking task led people to feel worse right after doing it, not better. It seems bracing simply doesn't work when it comes to our emotions.

This is actually relevant to a topical issue of our age to do with trigger warnings. The logic behind these warnings is that they'll allow people to brace themselves for difficult emotional experiences, such as sensitive topics or upsetting material in plays, books or films. Time and again, however, research has shown that trigger warnings are not effective at helping people protect themselves emotionally.

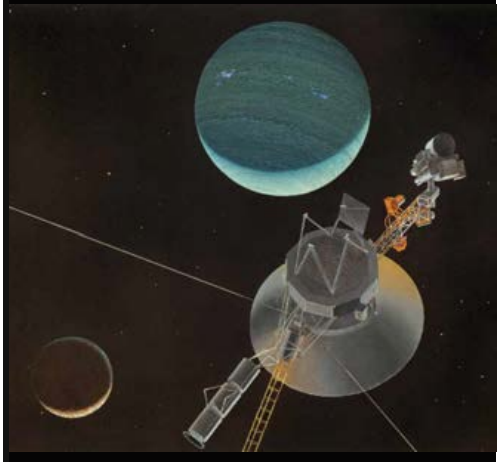
You might still be wondering about the dangers of over-optimism or complacency. The good thing about optimism is that it tends to drive motivation. If you think you have a chance of doing well in the exams, you're more likely to put effort into studying for them.

Researchers have shown this in studies with students: those who are more optimistic tend to put more effort into their studies, and then they tend to get better grades as a result. In other words, optimism can become self-fulfilling.

An important message from this optimism research is to remember the effort part of the equation. Unfounded, lazy optimism – simply hoping for the best and leaving it at that – isn't a good strategy. Thinking positively and investing the necessary effort to do well? Now that is a winning formula. ***CJ***

ELOUISE PACE, ST ALBANS

HOW CAN WE STILL TALK TO VOYAGER 2, WHEN IT'S BILLIONS OF MILES AWAY?



NASA communicates with all its space probes, including Voyager 2, with the Deep Space Network (DSN), a set of radio dishes at three sites around the world; Goldstone in California, Robledo near Madrid and Tidbinbilla near Canberra.

Since Voyager 2 is only visible from the southern hemisphere, an antenna called DSS-43, at the Australian site, is the only antenna on Earth that can send and receive signals to/from the probe.

The transmitter on Voyager 2 – currently more than 20 billion km from Earth – has a power of about 23 Watts (about eight times that of a typical mobile phone). By the time the radio signal reaches Earth it has about one-tenth of a billion-trillionth of this power.

In order to detect this extremely faint signal, DSS-43 and the transmitter on Voyager 2 are highly directional and use narrow-band, high-frequency signals transmitted at a slow bit-rate. Complex signal processing techniques, a lack of interference and the fact that radio signals travel almost unimpeded through space, means the vast distance is no obstacle for DSS-43. The antenna transmits signals to Voyager 2 at much higher power than it receives – up to about 400,000 Watts – easily heard by the distant probe. ***AG***

HERMAN TOWNSEND, LIVERPOOL

WHAT IS ASHEN LIGHT?

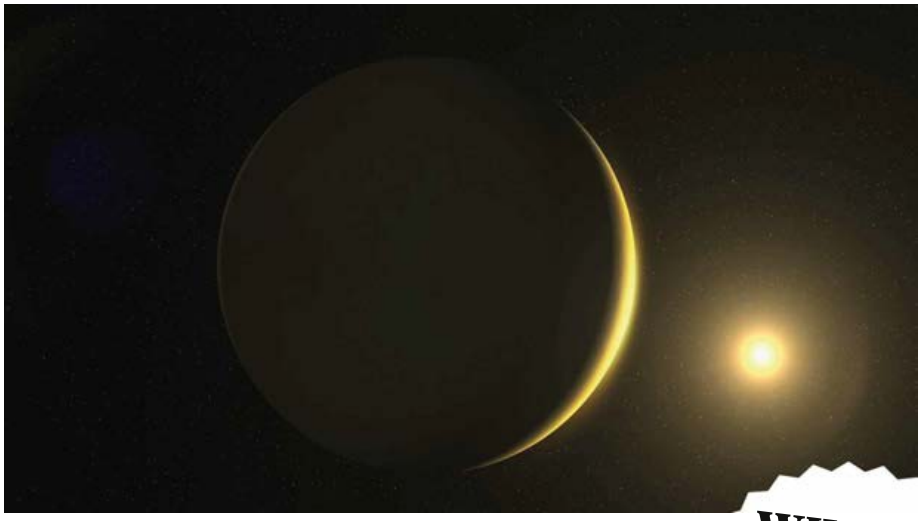
The 'ashen light', or AL, is a faint, mysterious glow, or colouration, seen in the night-side hemisphere of the planet Venus. It's often compared to the reflected 'Earthshine' that sometimes illuminates the dark-side of the Moon. First reported in 1643 by Italian astronomer Giovanni Riccioli, AL has been observed many times since, but its faint, transitory and elusive nature has prevented serious study. More problematically, AL has only ever been detected by the human eye and no scientific instrument, either Earth-based or space-based, has ever recorded the phenomenon.

Some authorities have declared the phenomenon illusory, perhaps a contrast effect for the eye, or even 'expectation bias'. Others suggest that instrumental defects may explain the phenomenon; light scattering, optical aberrations, the brightness of the background sky, weather and so on.

There are, however, enough credible reports of AL for some scientists to have offered explanations. These include reflected light from the Earth, aurorae, 'airglow' emission, lightning and infrared (heat) emission from the Venusian atmosphere.

Most of these explanations have been discounted for one reason or another. However, there's good evidence that energetic solar wind particles, as well as ultraviolet light from the Sun, can excite oxygen atoms in the Venusian atmosphere. This creates a faint green glow like that seen in aurorae on Earth. The process is somewhat different, though, since aurorae on Earth are due to the planet's magnetic field interacting with solar particles, while Venus has no appreciable magnetic field.

Whether this explanation can account for all, or any, observations of AL is yet to be seen. So the long-standing mystery of AL may yet prove to be an illusion. ***AG***



QUESTION OF THE MONTH

BILLY WILSON, VIA EMAIL

IF MY BRAIN WAS IN MY STOMACH, WOULD I 'THINK FROM MY STOMACH'?

The brain hasn't always been accepted as the organ of thought. The ancient Egyptians thought the heart was in charge of intelligence and contained the soul, so mummified bodies were preserved with the heart intact, but the brain removed and discarded. The Greek scholar Alcmaeon of Croton was among the first to make the case for the brain, in the 5th century BCE, but two centuries later, Aristotle was still arguing that the heart was the centre of intellect.

There's no rule that says thought has to have a centre at all. Octopuses have about two-thirds of their neurons distributed among their tentacles. This means that each arm can react to stimuli and move in a semi-independent way. Then there's the recent developments with AI models, such as ChatGPT, that have produced behaviour that looks a lot like conscious thought, with no physical sensory organs involved at all.

Modern neuroscience and medical imaging have now determined that, in humans at least, perception, thought and language are all controlled and coordinated by the brain. But what we think *with* is not quite the same as where we think *from*.

The western idea that consciousness originates in our heads is subjective and depends on culture and religion, too. Many indigenous cultures see consciousness as connected to a spirit or ancestral realm, separate from the body. There are also plenty of physical sensations such as hunger and pain that originate elsewhere in the body, yet we have no problem integrating this information with the thoughts in our head.

If our brains and stomachs had always been the other way around, we might think of the head as simply a collecting point for sensory and food inputs, while conscious thought was, quite naturally, located in the centre of our bodies. ***LV***

WINNER

The winner of next issue's *Question of the Month* wins a **Majority Snowdon II soundbar**. This 120W soundbar has a built-in subwoofer to provide an audio experience your TV can't deliver on its own – worth £80.

EMAIL YOUR QUESTIONS TO **QUESTIONS@SCIENCEFOCUS.COM**

GETTY IMAGES, SCIENCE PHOTO LIBRARY, ALAMY ILLUSTRATION: PANAGIS MATSANGOURAS

WHO DO YOU THINK YOU ARE? MAGAZINE

3 ISSUES FOR £5

When you subscribe to
Who Do You Think You Are? Magazine today!

Great Reasons To Subscribe Today

- ✓ Receive your first **3 issues for only £5***
- ✓ After your trial, continue to save **over 20%** on the shop price when you pay by Direct Debit
- ✓ Build a library of expert family history **advice and tutorials**
- ✓ **Never miss an issue** of the UK's bestselling family history magazine

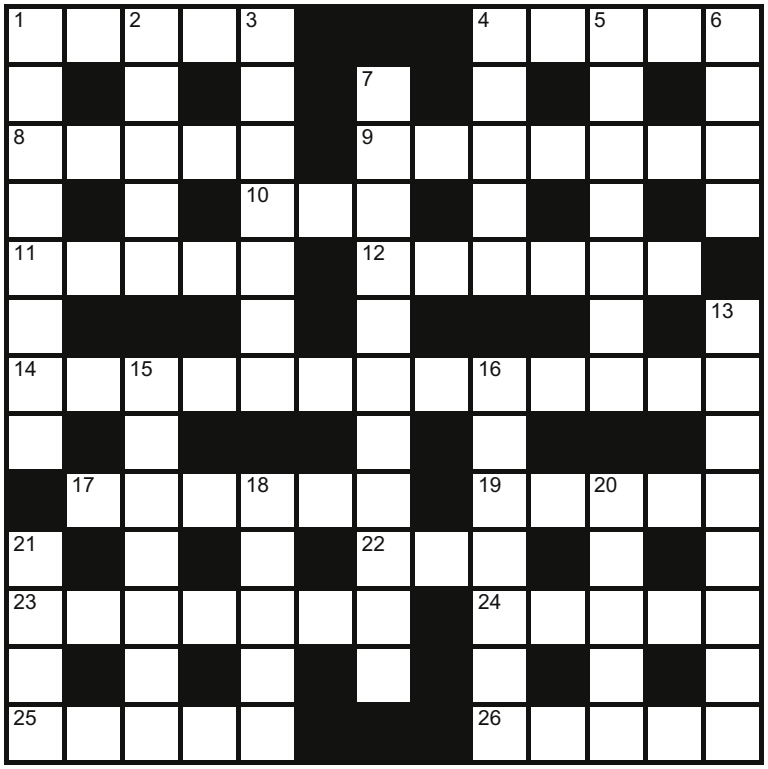
SUBSCRIBE ONLINE
www.buysubscriptions.com/WHHA23

BY PHONE
03330 162120†
QUOTE CODE WHHA23

*All savings are calculated as a percentage of the Basic Annual Rate. The UK Basic Annual Rate is £68.25 which includes event issues (issues charged higher than standard cover price) published in a 12-month period. This special introductory offer is available to new UK residents via Direct Debit only and is subject to availability. Offer ends 31 December 2023. The magazine used here is for illustrative purposes only – your subscription will start with the next available issue. After your first 3 issues, your subscription will continue at £24.99 every 6 issues thereafter, saving over 20% off the shop price. Full details of the Direct Debit Guarantee are available upon request.
†UK calls will cost the same as other standard fixed-line numbers (starting 01 or 02) and are included as part of any inclusive or free minutes allowances (if offered by your phone tariff). Outside of free call packages call charges from mobile phones will cost between 3p and 55p per minute. Lines are open Monday to Friday 9am–5pm

CROSSWORD

PENCILS AT THE READY!



ACROSS

1 Jacket loses tail in conflagration (5)
4 People first to rally for competitor (5)
8 Notice party has to improvise (2-3)
9 Tons about time for performing (2-5)
10 Feature of alarming weapon (3)
11 Instrument is returning to sailor (5)
12 Change Greek character at gallery (6)
14 Nocturnal bear turned out to be eco-friendly (6,7)
17 Item of crockery has a taste (6)
19 Hoard money, we hear (5)
22 Enthusiast from Brazil, say (3)
23 City cat relaxes outside (7)
24 Stupid tavern has a point (5)
25 Saying Frenchman joined German (5)
26 Observes stone being thrown (5)

DOWN

1 Swede, say, forced CIA to follow money (8)
2 Distribute a great deal, by the sound of it (5)
3 Stop me returning to pub and leave (7)
4 Tries desperately to take exam again (5)
5 Idle talk about milliner (7)
6 Wild hare and bird (4)
7 Sound judgment is feeling green, initially (6,5)
13 Ignorant, not having one of these? (8)
15 Chaotically, I dreamt to let in again (7)
16 Symbol of investiture in intersection without leader (7)
18 Morag groaning about stroppy behaviour (5)
20 Freewheel by the shore (5)
21 Seafood served in fantastic lamb (4)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW**
Please be aware the website address is case-sensitive.

BETTER LIVING THROUGH SCIENCE

HELLO DARKNESS, MY OLD FRIEND

With the evenings drawing in, could embracing the darkness be good for you?

It's that time again. The clocks have gone back and many of us are reaching for the SAD lamps, vitamin D supplements and carb-heavy one-pots to get us through the long, dark nights of winter.

But maybe there's another way to approach the change of season. What if we embrace the darkness?

At the right times and in the right quantities, darkness helps our bodies rest and heal, optimises our cognition and mental health, and lowers our risks of various illnesses.

That's because our circadian rhythms, or body clocks, are triggered not just by light, but also the lack of it.

"To optimise your sleep you want to keep it as dark as possible with as few distractions as possible," says Prof Victoria Revell, who researches circadian physiology at the Surrey Sleep Research Centre. "We know there are health implications to having constantly interrupted sleep. It's associated with things like cardiovascular disease, type 2 diabetes and increased cancer risk."

In 2022, researchers at Northwestern University found that exposure to even moderate light during sleep can harm your cardiovascular function (the light stimulates the sympathetic nervous system, elevating your heart rate and creating insulin resistance in the morning).

"LIKE MANY ANIMALS, HUMANS' NATURAL SLEEP-WAKE CYCLE EVOLVED IN SYNC WITH THE PATTERN OF DAY AND NIGHT"

Another study at Harvard University found that blood sugar levels increase when you're exposed to light at night.

Artificial sources of blue light, such as smartphones and similar devices, are thought to have the same stimulating effect on our bodies as daylight. The research into this isn't conclusive yet, but one study in 2017 saw researchers from the University of Colorado Boulder take a group of volunteers camping, away from city lights and without smartphones or torches. Campfire was the only additional light permitted. The study found that the camping trip 'reset' the volunteers' body clocks, with people sleeping and waking in time with their circadian rhythms.

Like many animals, humans' natural sleep-wake cycle evolved in sync with the pattern of day and night. And just as morning light stimulates alertness, and supports immune function and mental health, the body also responds to the dark. For example, melatonin (aka the Dracula hormone) is produced by the pineal gland in direct response to darkness.

In the Colorado study, the campers began to produce melatonin two hours earlier. "Melatonin is associated with opening the 'sleep gate'," says Revell. "It begins the process of winding down and getting ready for sleep."

It's also the subject of research into a range of health conditions. The picture is incomplete, but higher levels of melatonin are associated with a lower risk of heart disease and certain cancers.

If we're suffering from darkness deficiency, switching to a permanent dark mode isn't the answer, either. Research shows that night-shift workers and others confined to darkness have a higher risk of diseases including diabetes, heart disease and obesity.

In short, we need both light and dark, and we need them at the right times. Some researchers suggest that the solution is a kind of 'paleo lighting', living like our ancestors by maximising daylight in the day and keeping things dark at night.

As the nights draw in, how's that for a light bulb moment? **SF**

TAKEAWAY ADVICE

Improve your chances of getting a good night's sleep by seeking out natural light in the day and steering clear of artificial light after dark.

by **IAN TAYLOR**

Ian is a freelance science writer and the former deputy editor of BBC Science Focus.

ILLUSTRATION: JOE WALDRON

THE CLIMATE CRISIS IS A STARK REALITY FOR PEOPLE LIKE SEID

TREE AID

Land. Lives. Futures. All devastated.

But climate champions across dryland Africa are rising together. Growing trees, protecting land, and improving their income.

DONATE NOW AND JOIN US IN SHAPING A BETTER FUTURE FOR PEOPLE AND THE PLANET.

Visit www.treeaid.org/trees or scan here

Tree Aid, Brunswick Court, Brunswick Square, Bristol, BS2 8PE.
Registered Charity No. 1135156. Company Registration No. 03779545.